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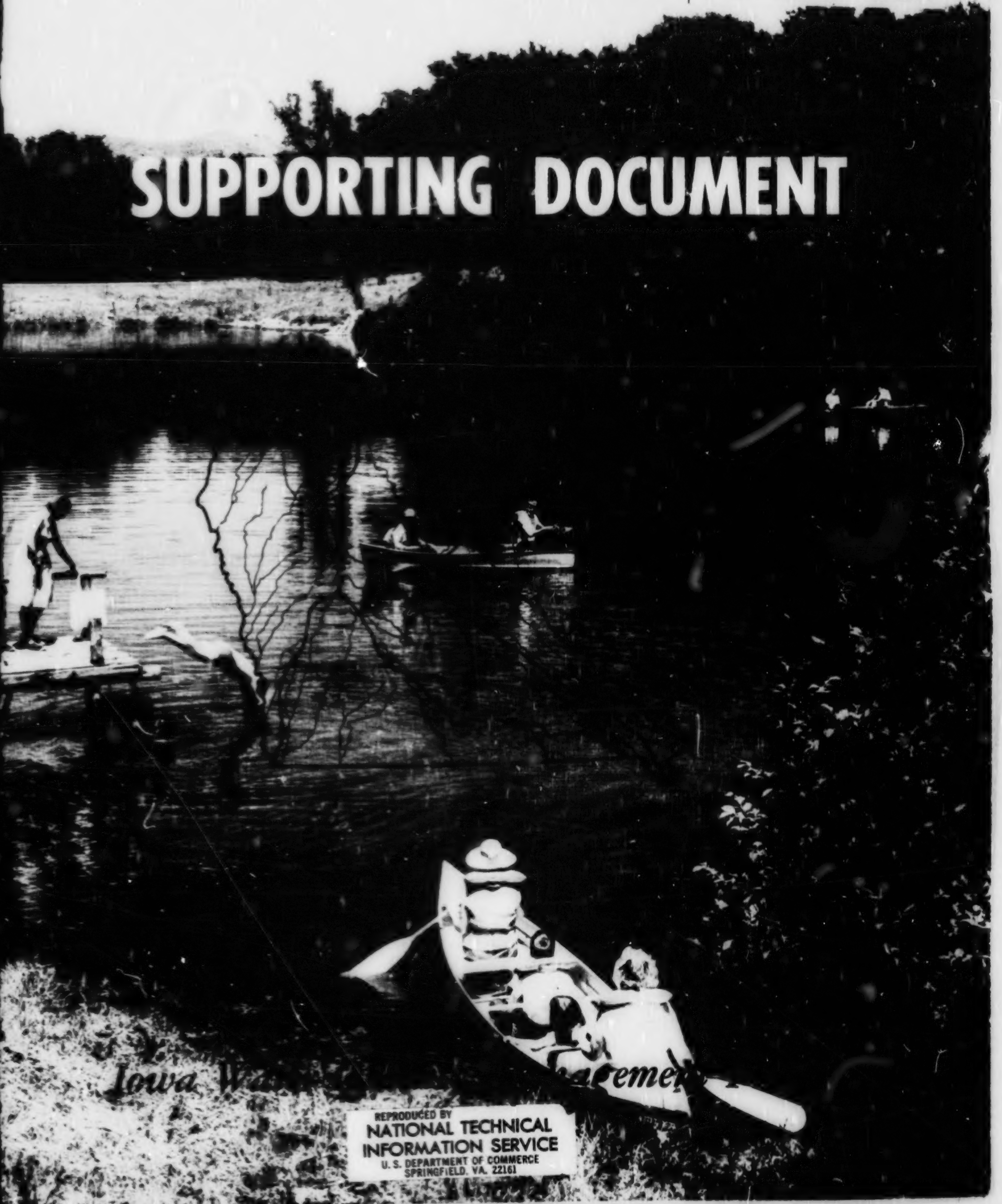
Iowa Water Quality Management Plan Supporting Document

Iowa Dept of Environmental Quality, Des Moines

Jul 76

PB 264 680

SUPPORTING DOCUMENT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16. ABSTRACT

This supporting document contains general information applicable to all of the basin plans for the six major river basins partially located in Iowa. This includes climatological, geological and hydrological information.

17. KEY WORDS AND DOCUMENT ANALYSIS

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SUPPORTING DOCUMENT
FOR
IOWA WATER QUALITY MANAGEMENT PLANS

July, 1976

PLANNING AND ANALYSIS SECTION
WATER QUALITY MANAGEMENT DIVISION
IOWA DEPARTMENT OF ENVIRONMENTAL QUALITY

i-a

FOREWORD

Under section 455B.31, Code of Iowa, 1973, the Iowa Department of Environmental Quality (DEQ) is charged with the responsibility of protecting and maintaining surface and ground water quality throughout the State. To assist the Department in this task, basin plans are prepared to coordinate and direct the State's water quality management decisions on a river basin scale.

Six major river basins, as defined by the Department of Environmental Quality, are partially located in the State of Iowa (Figure 1). Basin plans for the six major basins are prepared by the Water Quality Management Division of the DEQ. The plans include a determination of existing water quality, applicable standards, and significant point and nonpoint sources of pollution in the basin. The plans then identify and set forth measures to correct the water quality problems of each basin.

This document contains general information applicable to all of the six basin plans. The information is essentially of a supporting or background nature and was not considered to warrant duplication in each of the basin plans.

The national goal, established in the Federal Water Pollution Control Act Amendments of 1972, (the Act), provides for water quality suitable for the protection and propagation of fish and wildlife, as well as for recreational activities in all surface waters by July 1, 1983. The Amendments define basin

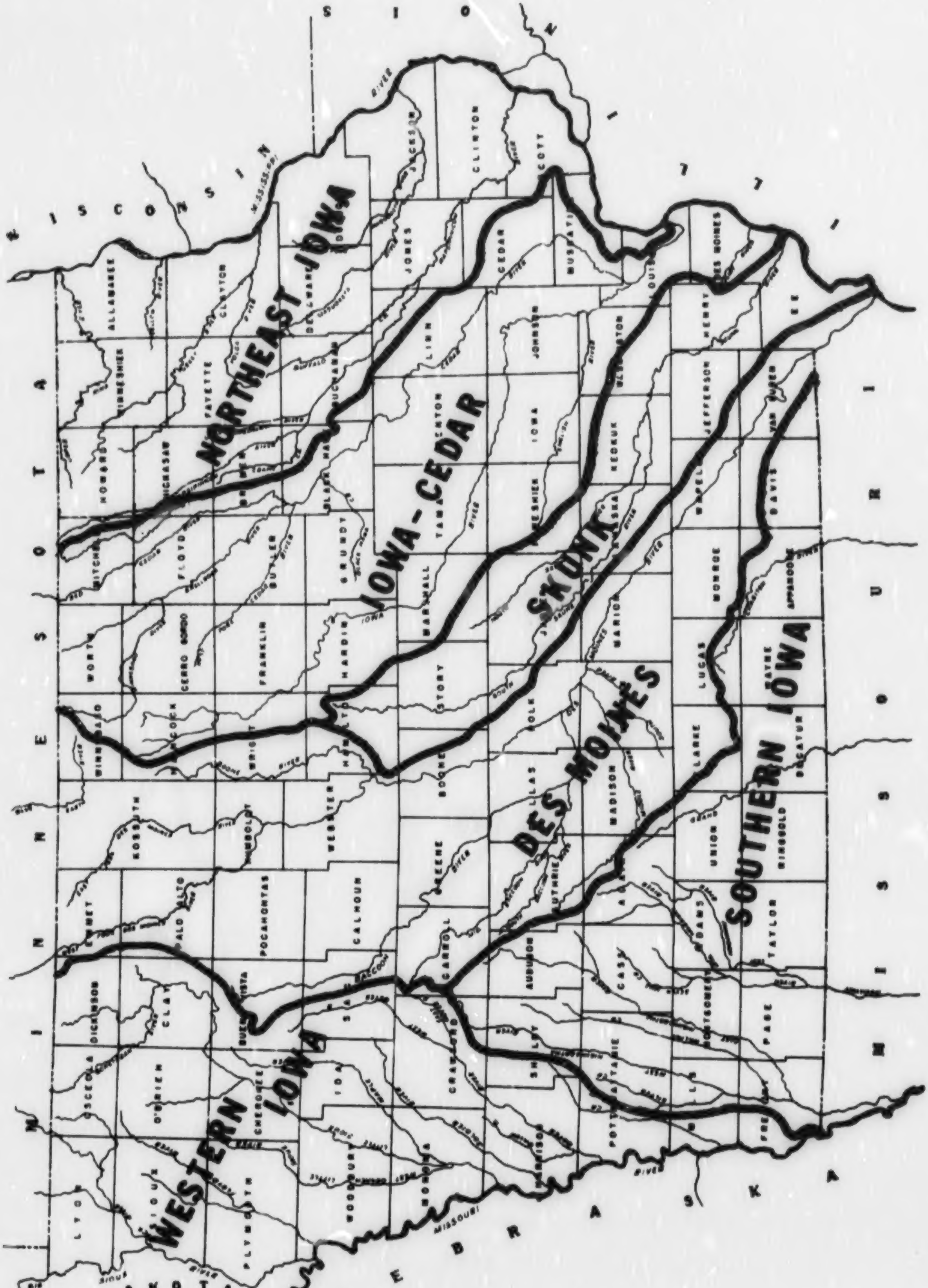
NORTHEAST IOWA
IOWA-CEDAR
SKUNK
DES MOINES
SOUTHERN IOWA
WESTERN IOWA
MINNESOTA
WISCONSIN
ILLINOIS
MISSOURI
NEBRASKA
S. DAKOTA

FIGURE 1

planning (Section 303(e)) as a key element for the determination and implementation of the necessary requirements to achieve national water quality goals.

The basin plans are specifically directed towards satisfying requirements of Section 303(e) of the Federal Water Pollution Control Act, as amended; Public Law 92-500, 86 Statute 816 (1972); (33 United States Congress 1251 *et sequens*). The basin plans will serve local and regional governments as well as State and Federal agencies.

SCOPE

The scope of this document entails a discussion of the following items: (1) General Characteristics of Iowa, (2) Water Quality, (3) Nonpoint Pollution Sources, (4) Segment Analysis Methodology & Wasteload Allocations, and (5) Treatment Alternatives. The document contains detailed background information and information of a general nature not deemed necessary to be included in each of the six basin plans. The detail of study of this document is as follows:

I. General Characteristics of Iowa

The physical characteristics of Iowa including climatology, hydrogeology, and ground water quality, are discussed.

II. Water Quality

Iowa Water Quality Standards and Stream Classifications are delineated. Available water quality data have been accumulated and evaluated to present the best possible picture of the recent history of Iowa water quality. Existing water quality is described and then compared with the Iowa Water Quality Standards.

III. Nonpoint Pollution Sources

The problems of nonpoint pollution sources are addressed. Combined sewer overflows, urban runoff, and rural sources of pollution from animal feeding operations and general agricultural activities are characterized. Based upon information extrapolated from other areas, the potential pollution from typical sources is identified.

IV. Segment Analysis Methodology and Waste Load Allocations

The water quality modeling techniques and assumptions used to evaluate the impact of wastewater discharges upon stream quality under low flow conditions are discussed.

V. Treatment Alternatives

Various wastewater treatment processes are described. A general discussion of arrangements for upgrading existing facilities is presented for use by city officials in the evaluation of alternative approaches to achieving required effluent quality.

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CHAPTER I - GENERAL CHARACTERISTICS OF IOWA

Iowa is situated in the Missouri and Upper Mississippi River drainage basins, bounded on the east by the Mississippi River and on the west by the Missouri and Big Sioux Rivers. In general, the surface shows but slight relief with the highest point in the northwest corner (1,675 feet) and the lowest point in the southeast corner (480 feet).

The entire State is drained by either the Mississippi River or its tributary, the Missouri River. Streams flowing to the Mississippi River flow in a general course from northwest to southeast. The major drainage basins are long and narrow and have fairly regular outlines with the lateral boundaries tending to be parallel. The streams which flow into the Missouri River, flow from the northeast to the southwest and are also relatively long and narrow.

GENERAL CLIMATOLOGY

The information for this section is taken from several articles (1, 2, 3, 4) written by Paul J. Waite, former climatologist for Iowa.

Iowa's climate, because of latitude and interior continental location, is characterized by marked seasonal variations. During the 6 warm months of the year the prevailing moist, southerly flow from the Gulf of Mexico produces a summer rainfall maximum. The prevailing northwesterly flow of dry Canadian air in the winter causes this season to be cold and relatively dry. At intervals throughout the year, air masses from the Pacific Ocean moving across the western United States reach Iowa, producing comparatively mild and dry weather. The autumnal "Indian Summers" are a result of the dominance of these modified Pacific air masses. Hot, dry winds, originating in the desert southwest United States, occasionally sweep into Iowa during the summer producing unusually high temperatures and desicating crops.

Wind Patterns (1)

Since Iowa is located under or near the storm tracks all year, atmospheric pressure differences readily produce winds that occur almost all the time. Figures I-1 and I-2 show the prevailing seasonal winds, and the monsoon-like change in direction is quite evident. The cool season of November through April is characterized by a northwesterly flow across Iowa that diminishes southeastward into Illinois and Indiana due to the northeasterly motion of a number of winter storms originating in the Texas-Oklahoma areas and moving northeastward into the Midwest and Great Lakes area. The warm seasonal flow from the south averages about two miles per hour less than the stronger winter motion. The mean annual flow in Figure I-3 indicates

FIGURE I-1

MEAN COOL SEASON (NOVEMBER-APRIL) SURFACE WIND DIRECTIONS AND SPEEDS IN MILES PER HOUR (1)

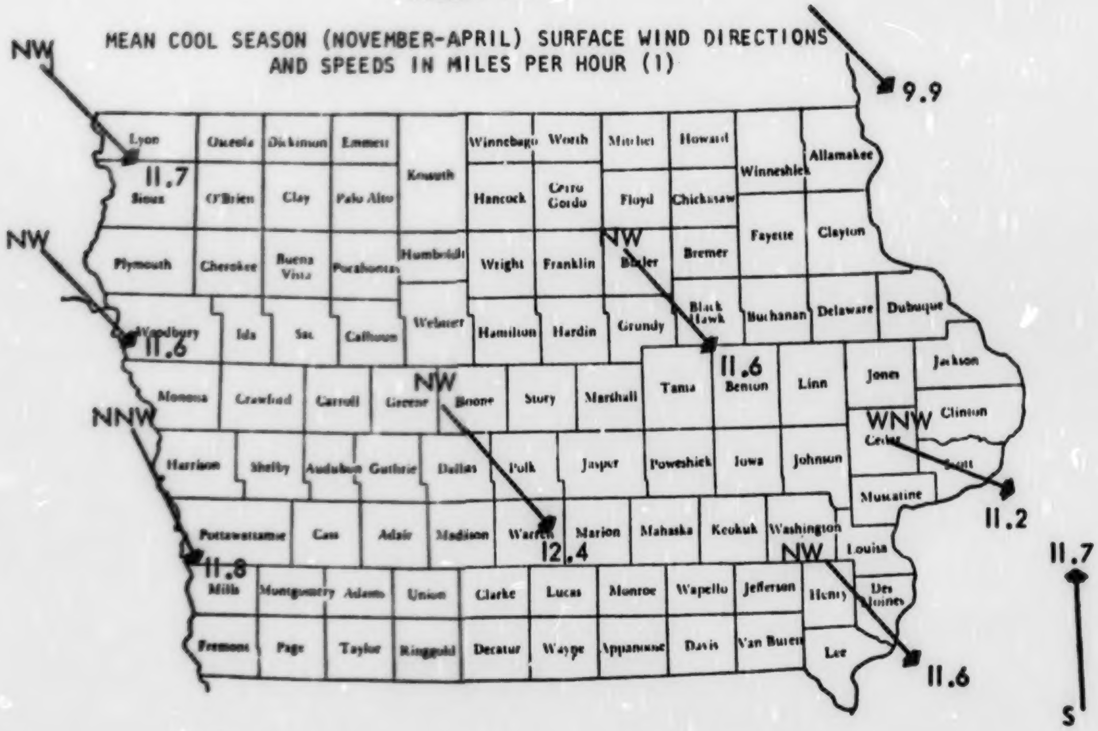
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FIGURE I-2

MEAN WARM SEASON (MAY-OCTOBER) SURFACE WIND DIRECTIONS AND SPEEDS IN MILES PER HOUR (1)

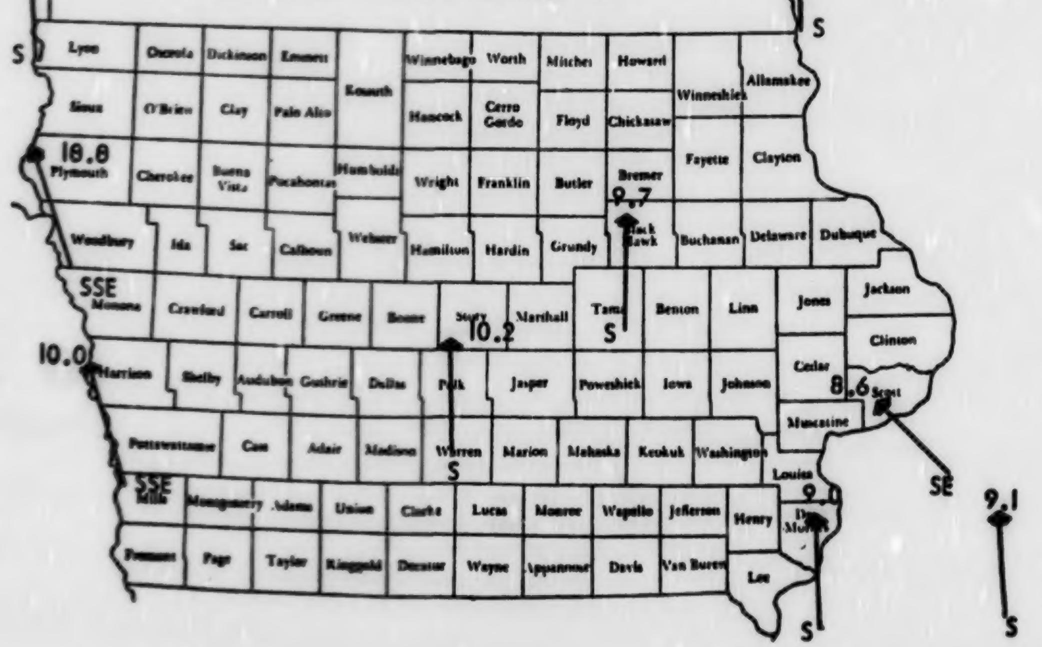
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FIGURE I-3

MEAN ANNUAL PREVAILING SURFACE WIND DIRECTIONS AND SPEEDS (MPH) (1)

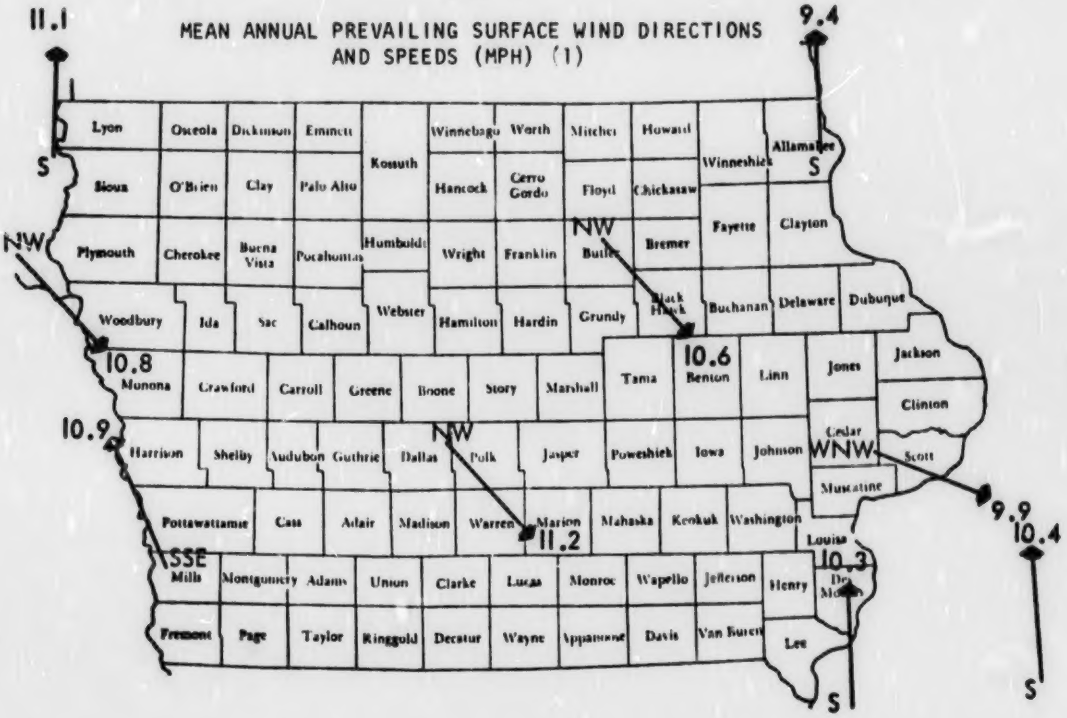
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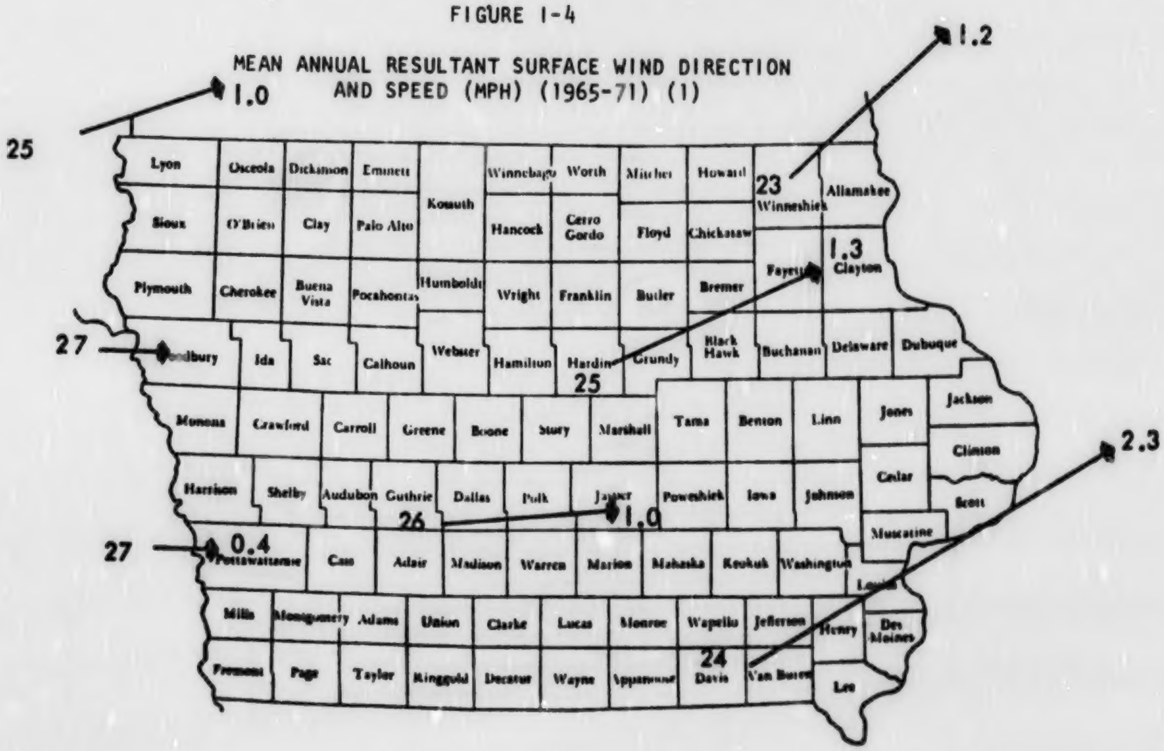
FIGURE I-4

MEAN ANNUAL RESULTANT SURFACE WIND DIRECTION AND SPEED (MPH) (1965-71) (1)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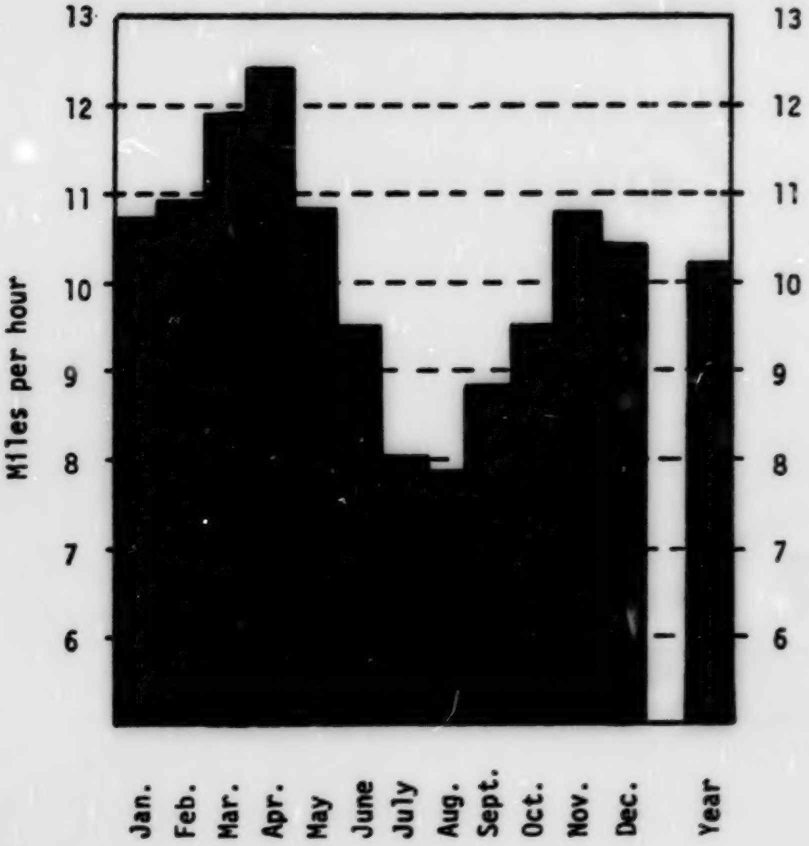
the near balance in seasonal duration of the two prevailing flows as shown by the mixture of southerly and northwesterly flow patterns. To measure the mean transport of air across Iowa the 1965-71 resultant winds are summarized and are shown in Figure I-4. The mean speeds, at or near the 20 foot anemometer level at all sites, indicate general west-southwesterly flow across Iowa averaging near one mile per hour and increasing in speed from west to east. A general wind speed profile for the state by months and for the year is presented as a general model (Figure I-5). At the level 20 feet above ground average monthly wind speeds vary from 7.8 miles per hour in August upward to 12.4 miles per hour in April, the latter slightly exceeding the wind motion of the traditionally windy March. The March-April annual wind peak coincides with the passing of winter into summer and the attendant proximity of the prevailing storm tracks across and near Iowa. The autumnal wind speed peak in November coincides with the rapid re-establishment of winter over Iowa and the associated prevailing northwesterly winds of winter.

Diurnal wind profiles for Iowa locations indicate that wind speeds are lowest in the early morning hours, between 1:00 and 6:00 a.m. Central Standard Time (CST), and reach peak speeds between 1:00 and 3:00 p.m. CST.

FIGURE I-5

IOWA COMPOSITE AVERAGE WIND PROFILE ADJUSTED TO 20 FEET ABOVE THE GROUND



Higher wind speeds, of 25 miles per hour or stronger, occur about three percent of the time over Iowa and about three times as frequently during early afternoon as at night. Winds of this velocity are consequential since property wind losses of minor nature begin at about 25 mph. Winds up to 80 miles per hour or higher are usually measured within Iowa each season (the average number of days for the years 1967 through 1971 was 27 days) and result in occasional deaths, an average of 22 injuries per season, and major crop and property losses.

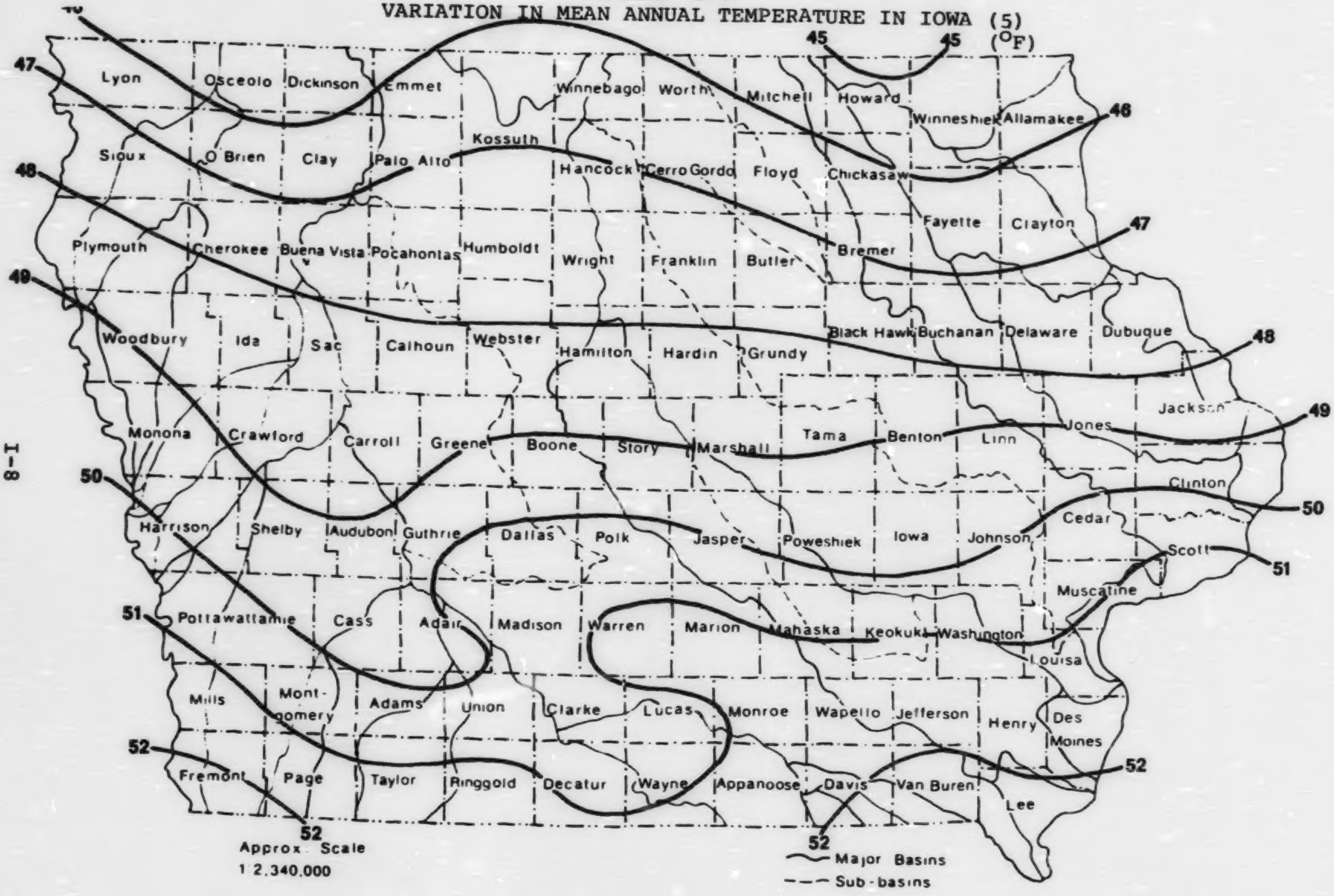
Temperature (2, 3)

The average annual temperatures range from 46° in the northern counties to 52° in the southeastern counties. In July, the hottest month, the average daily maximum is around 85° and the daily minima are mostly in the lower sixties. In January daily maxima range from 24° to 34°, north to south, and the minima from 4° to 14°. Variation in mean annual temperature is shown in Figure I-6. The mean minimum January temperature is shown in Figure I-7 and the mean maximum July temperature is shown in Figure I-8.

Extreme temperatures have varied from 118° at Keokuk on July 20, 1934, to -47° at Washta on January 12, 1912. In almost every year at some location in the State, a maximum exceeds 100° and a minimum of less than -20°

FIGURE I-6

VARIATION IN MEAN ANNUAL TEMPERATURE IN IOWA (5) (°F)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Major Basins
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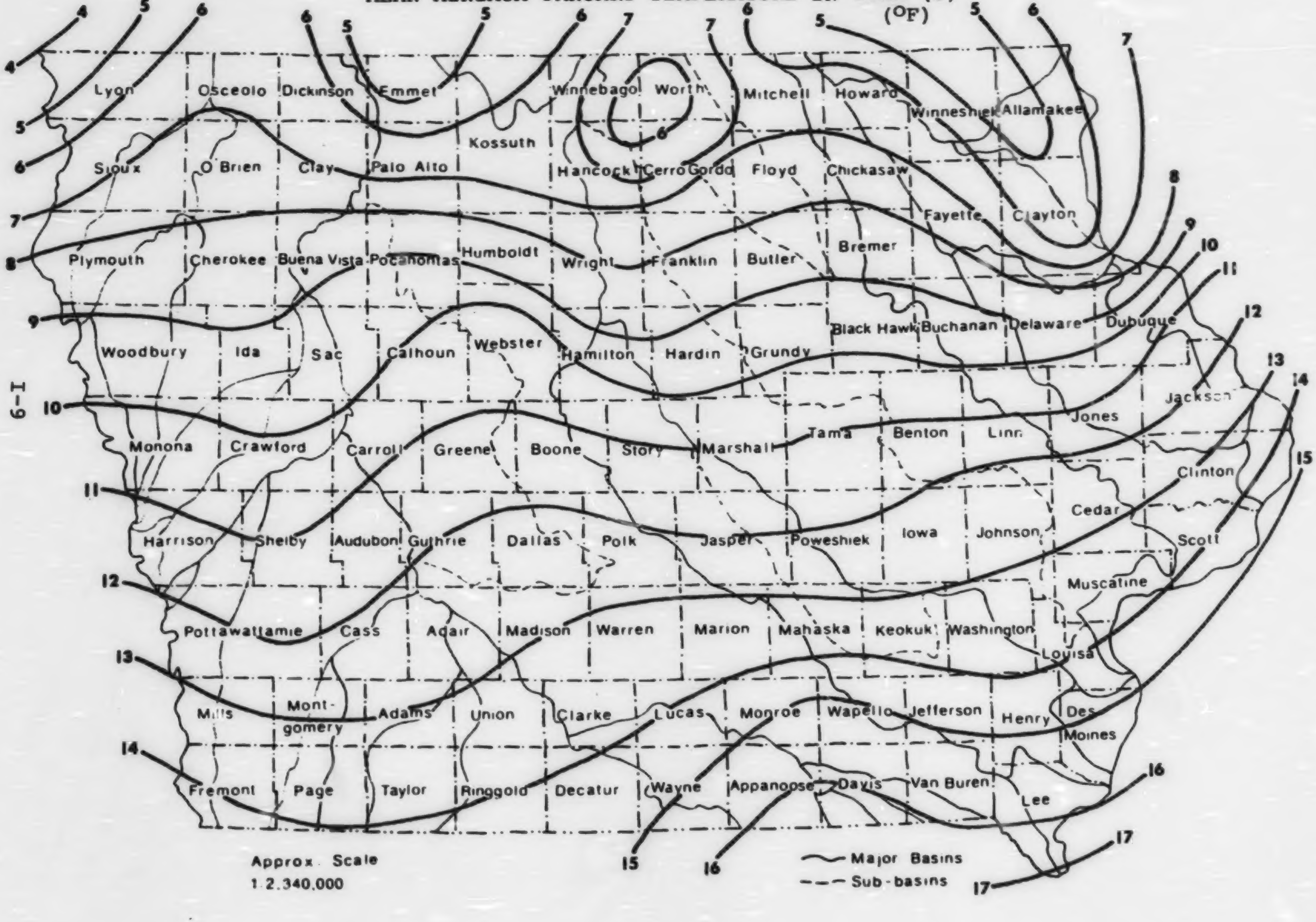
FIGURE I-7
MEAN MINIMUM JANUARY TEMPERATURE IN IOWA (6)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Major Basins
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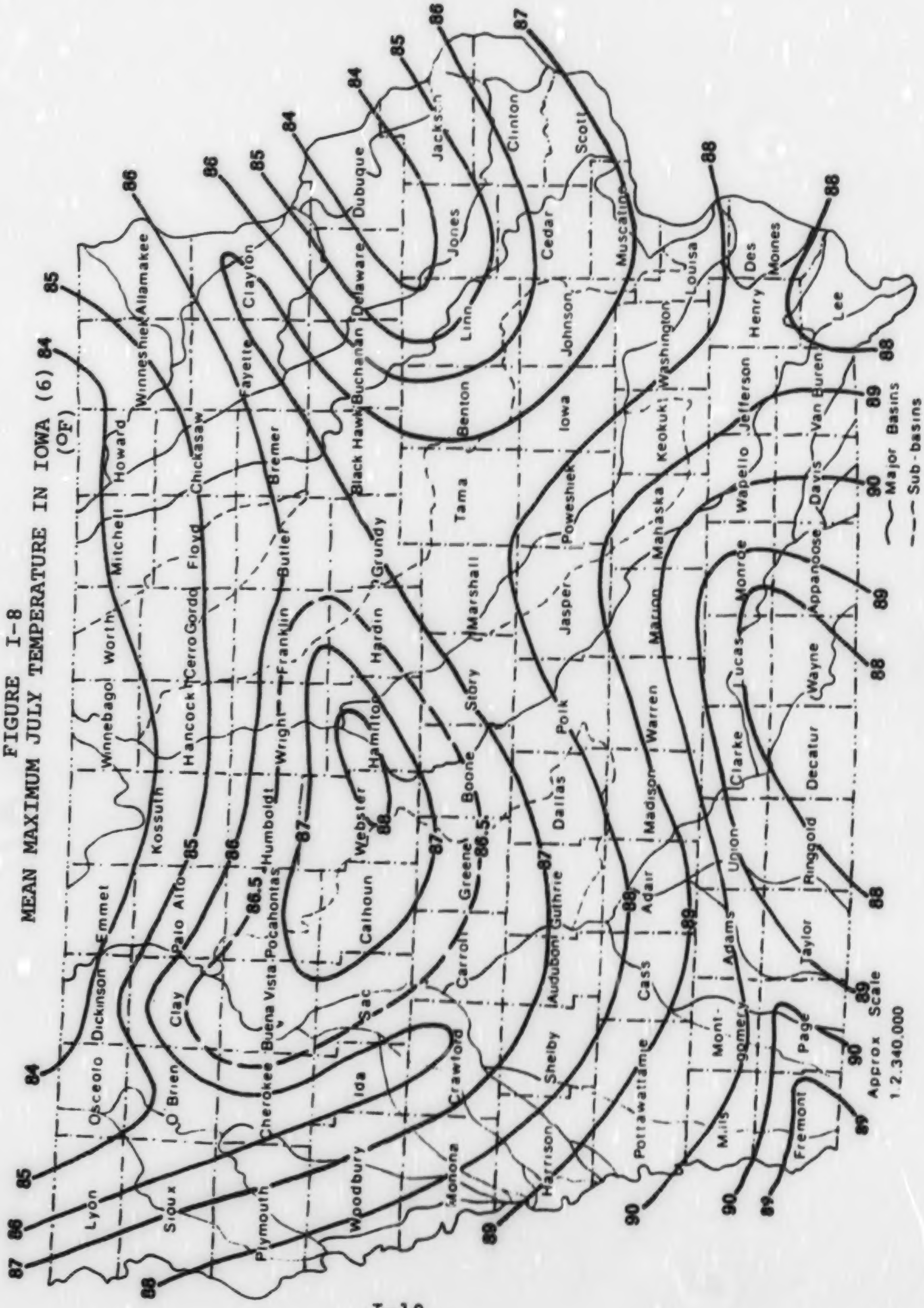
FIGURE I-8

MEAN MAXIMUM JULY TEMPERATURE IN IOWA (6)
(°F)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Winneshiek
Allamakee
Sioux
O'Brien
Clay
Palo Alto
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Black Hawk
Buchanan
Delaware
Dubuque
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Tama
Benton
Linn
Jones
Jackson
Clinton
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Cedar
Scott
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
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Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx Scale
1.2.340,000
Major Basins
Sub-basins

occurs. In half the years the maximum exceeds 104° and the minimum falls below -31°. The average number of days with temperatures 90° or higher range from 47 at Shenandoah to 6 at Waukon and Saratoga. The number of days with zero or lower temperatures range from about 10 per year in the south to 30 in the north.

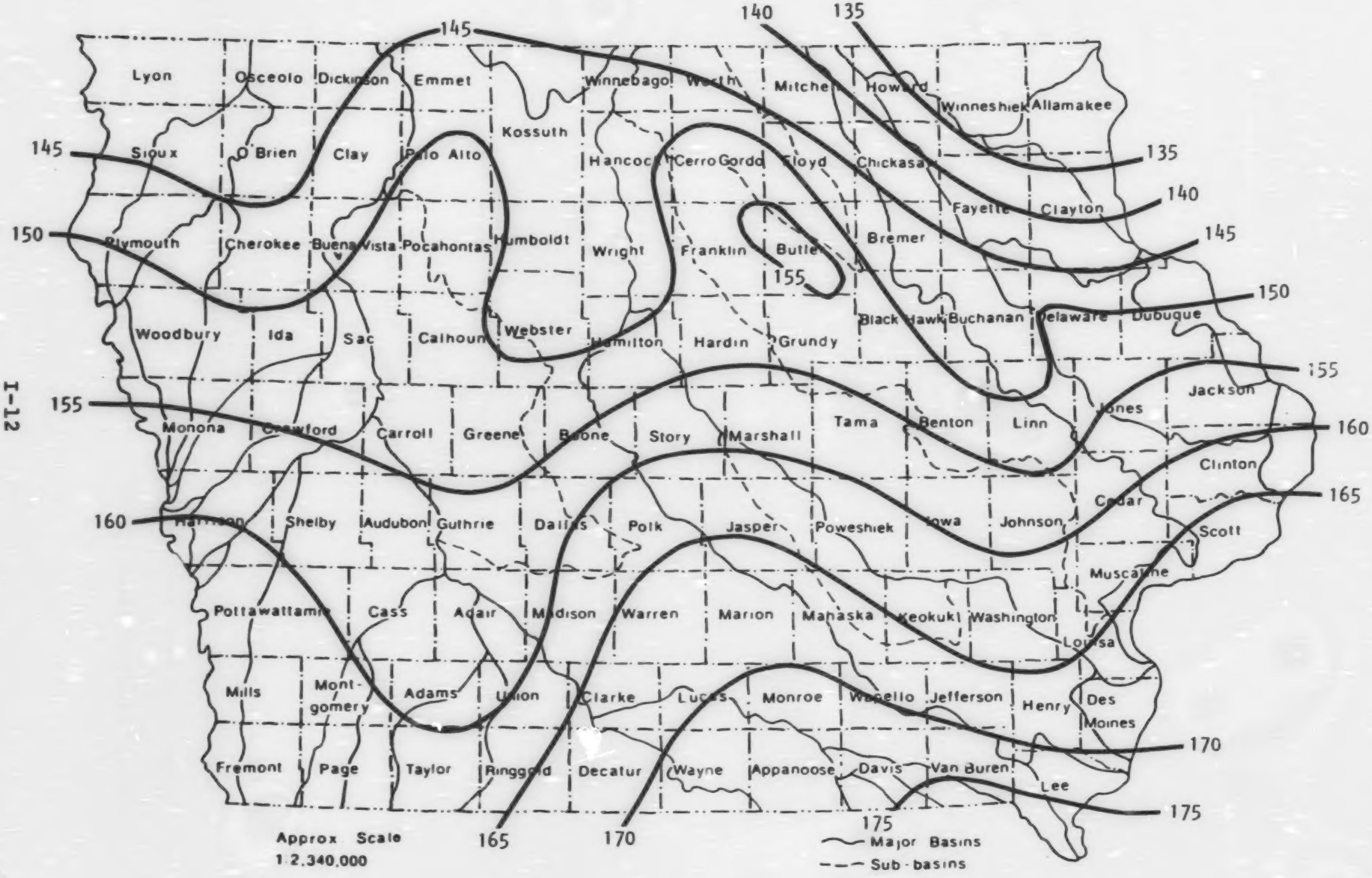
The growing season for warm weather crops extends from mid-May to early October. The spring growing season suitable for hardy crops, lasts approximately 6 weeks and the autumn season about 7. The dormant season, averaging 19 weeks, extends from mid-November to late March. The crop growing season is limited by both spring and fall freezes in Iowa. The average freeze-free season, last spring freeze, and first fall freeze are shown for the state in Figures I-9, I-10, and I-11, respectively.

Precipitation (2, 4)

Precipitation averages around 31 inches per year for the state, ranging from 23 inches in the extreme northwest to about 34 inches in the East Central and Southeast divisions (Figure I-12). However, annual totals vary widely from year to year and locality to locality. State averages since 1873 indicate that the driest year of record was 1910, averaging 19.89 inches while the wettest was 1881, averaging 44.16 inches (1858 may have been wetter than 1881). Since 1930 average state precipitation has varied from 22.77 inches in 1955 to 42.22 inches in 1951. Annual

FIGURE I-9 FREEZE FREE SEASON (3)

THE AVERAGE NUMBER OF CONSECUTIVE FREEZE FREE DAYS. 1941-70 BASE.


135
140
145
150
155
160
165
170
175
Lyon
Osceola
Dickinson
Emmet
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Kossuth
Sioux
O'Brien
Clay
Palo Alto
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
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Bremer
Woodbury
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Webster
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Hardin
Grundy
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Marion
Mahaska
Keokuk
Washington
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Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx Scale
1:2,340,000
Major Basins
Sub-basins

FIGURE I-10 LAST SPRING FREEZE (3)

THE AVERAGE DATE OF THE LAST 32° FREEZE IN THE SPRING. 1941-70 BASE.

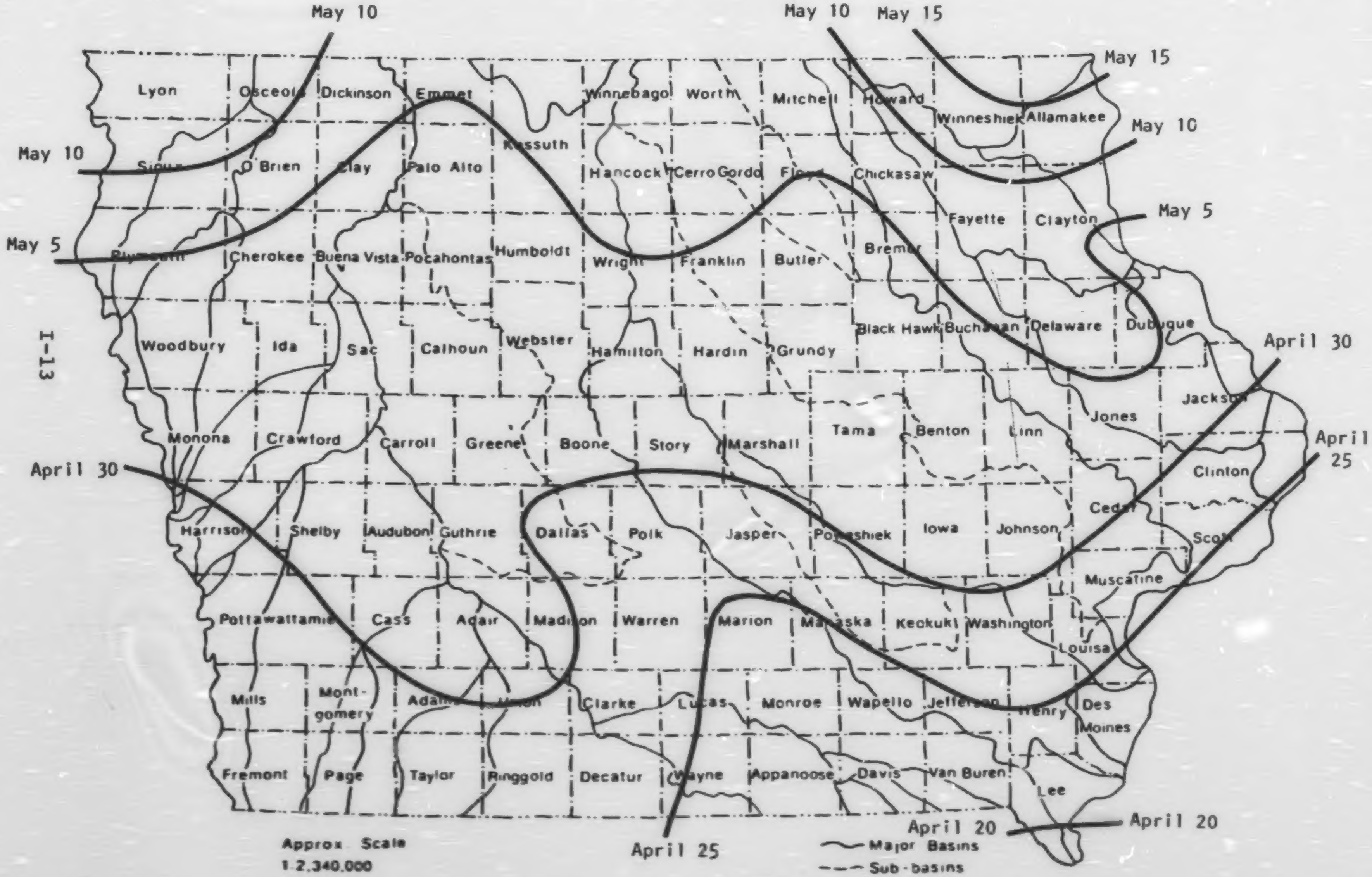

May 10
May 5
May 10
May 15
May 15
May 10
May 5
April 30
April 30
April 25
April 25
April 20
April 20
Lyon
Osceola
Dickinson
Emmet
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
Clay
Palo Alto
Kossuth
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Black Hawk
Buchanan
Delaware
Dubuque
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Tama
Benton
Linn
Jones
Jackson
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Clinton
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Cedar
Scott
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx. Scale
1:2,340,000
Major Basins
Sub-basins

FIGURE I-11 FIRST FALL FREEZE (3)

THE AVERAGE DATE OF THE FIRST 32° FREEZE IN THE FALL - 1941-70 BASE.

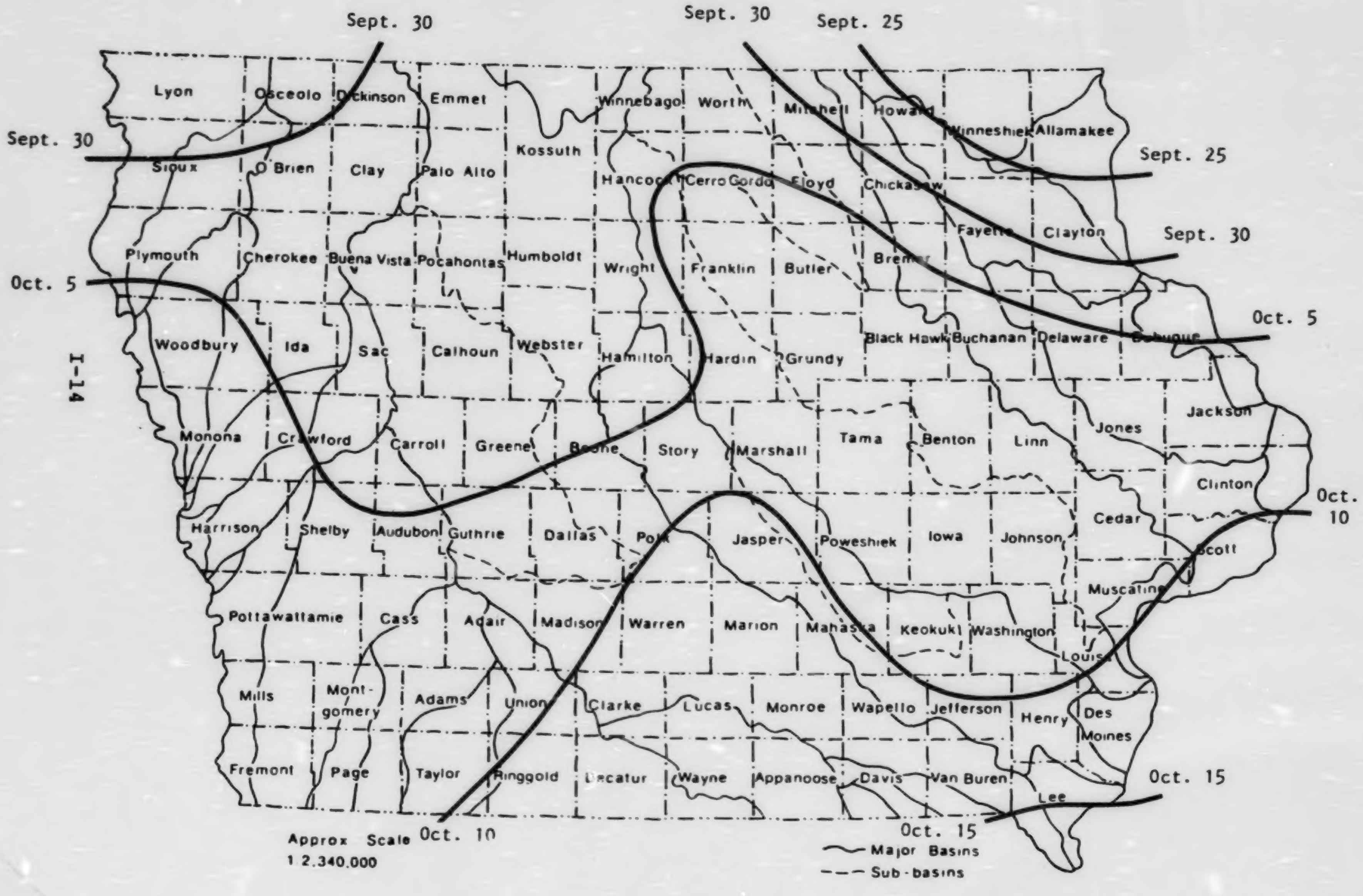
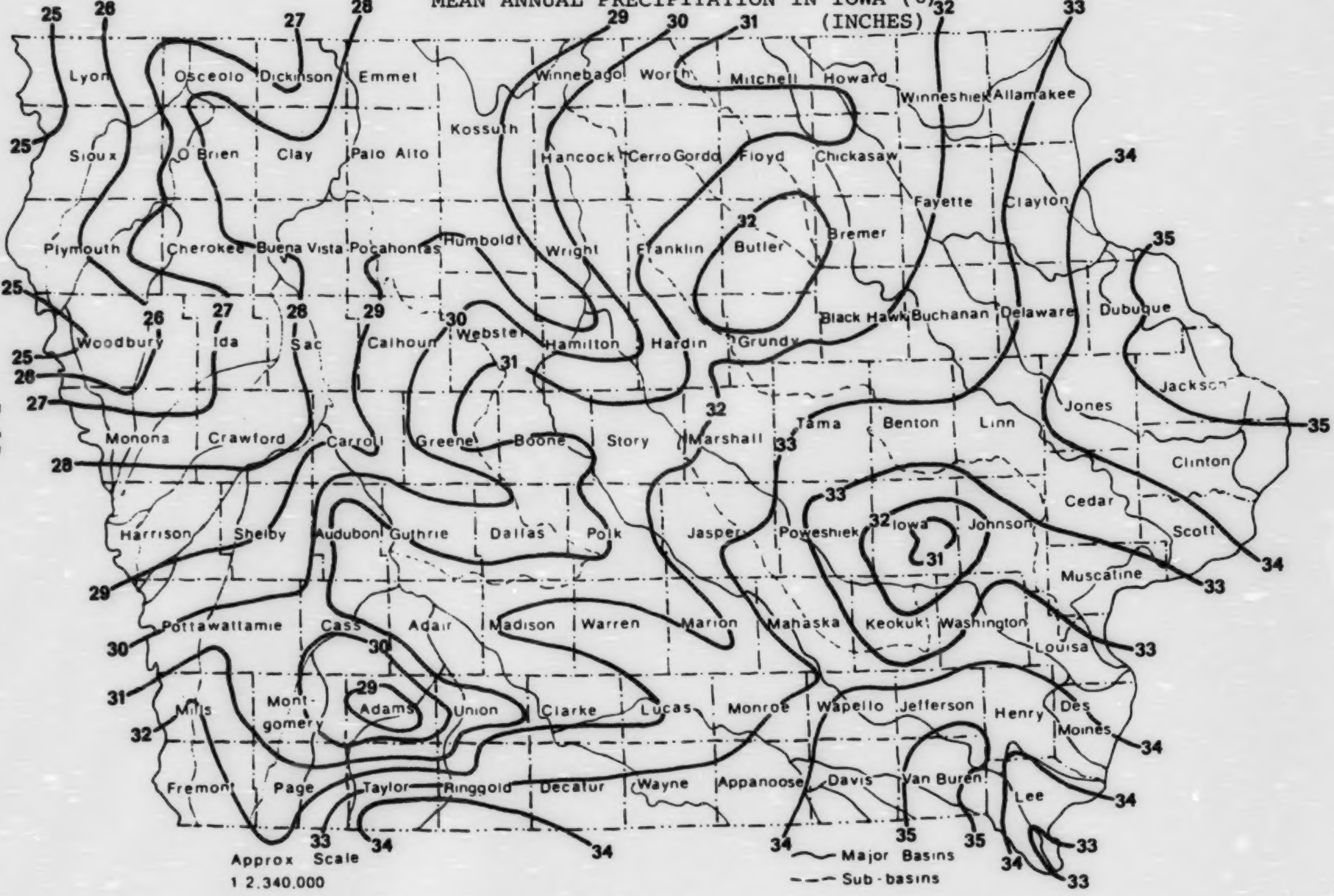

Sept. 30
Sept. 30
Sept. 25
Sept. 30
Sept. 25
Sept. 30
Oct. 5
Oct. 5
Oct. 10
Oct. 10
Oct. 15
Oct. 15
Lyon
Osceola
Dickinson
Emmet
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
Clay
Palo Alto
Kossuth
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Black Hawk
Buchanan
Delaware
Dubuque
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Tama
Benton
Linn
Jones
Jackson
Clinton
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Cedar
Scott
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Muscatine
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx Scale
1:2,340,000
Major Basins
Sub-basins

FIGURE I-12
MEAN ANNUAL PRECIPITATION IN IOWA (6)
(INCHES)


25
26
27
28
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30
31
32
33
34
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Lyon
Osceola
Dickinson
Emmet
Kossuth
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O Brien
Clay
Palo Alto
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Black Hawk
Buchanan
Delaware
Dubuque
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Jackson
Jones
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Tama
Benton
Linn
Clinton
Cedar
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Scott
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx Scale
1 2.340.000
Major Basins
Sub-basins

precipitation within Iowa has varied from 12.11 inches at Clear Lake in 1910 to as much as 74.50 inches at Muscatine in 1851.

The cyclic annual pattern of Iowa precipitation varies from little more than an inch in February to nearly five inches during June, a direct consequence of the availability of the moisture and the proximity of the eastward moving storms. During winter the storm track is more often displaced well to the south of Iowa, migrating northward with heaviest rainfalls in May and June and diminishing during July as the storms track across Canada. A secondary, but lesser, rainfall maximum is associated with the southward movement of the prevailing storm track across Iowa in August or September.

On nearly half of all the days in the year a trace or more precipitation falls at all Iowa locations. This approximates about two-thirds of the cloudy (about 160 days) and the partly cloudy days (100 to 105 days). Nearly two-thirds of the annual precipitation is measured during the 6 crop-months of April through September.

Except for the seasonal rainfall pattern with all its variations, rainfall (and snowfall) variation since 1873 does not exhibit a consistent pattern or trend.

Rainfall - The preponderance of rainfall days are with small precipitation amounts. Measurable rain occurs on about 100 days per year; the frequency of a tenth of an inch or more increases southeastward across the state from 44 days per year at Inwood, James, and Merrill to 69 days at Maquoketa (Figure I-13). Half an inch or more of rain per day varies from 15 days in the extreme northwest to near 25 in the southeast (Figure I-14).

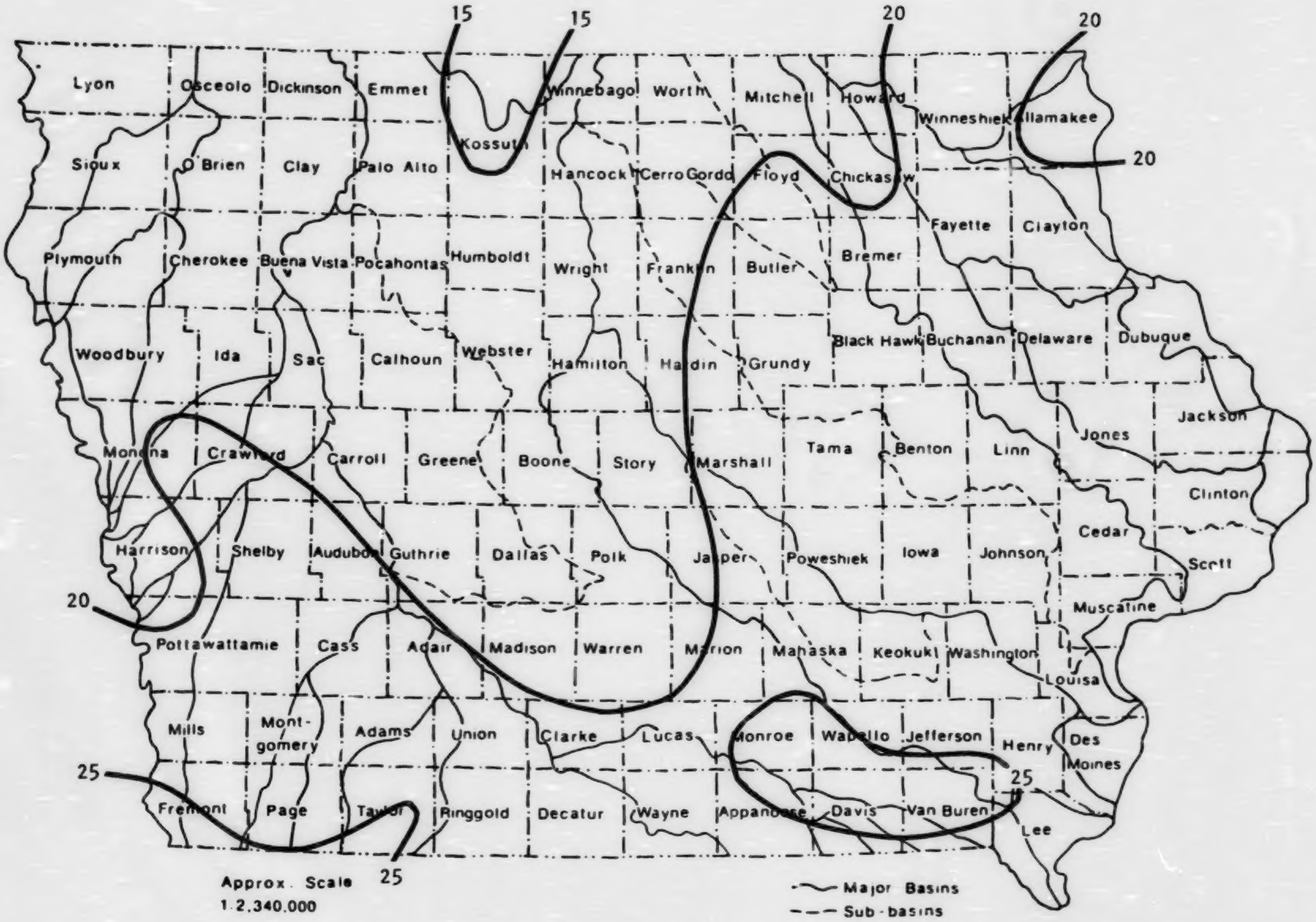
The probability of six inches of rainfall in a day at any particular Iowa point has a recurrence period approaching 100 years. The record 24-hour rainfall at any official rain gage location is 12.99 inches, measured at Larrabee on June 24, 1891. Unofficial gages in bucket surveys have yielded amounts in excess of 17 inches. Seven inches of rainfall in a week is about a once in ten year occurrence and a nine inch rainfall has a return period of about 50 years.

Thunderstorms - Most of Iowa's violent weather is associated with thunderstorms. The thunderstorm frequency increases with the seasonal increase in precipitation. Annually the thunderstorm days total about 40 days in the north to 50 days in the south occurring mostly during the warm months. Quite a large percentage of the Iowa thunderstorms are nocturnal.

Occasionally hail, high winds, heavy rains, and even tornados are associated with the thunderstorms. The probability of occurrence is highest in late spring and early summer. Tornado frequency is highest in May and

F!GURE I-13

MEAN NUMBER OF DAYS PER YEAR WITH PRECIPITATION EQUAL TO OR GREATER THAN 0.5 INCH (4)


15
15
20
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20
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25
25
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Lyon
Osceolo
Dickinson
Emmet
Kossuth
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
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Cerro Gordo
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Pocahontas
Humboldt
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Franklin
Butler
Bremer
Woodbury
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Calhoun
Webster
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Clinton
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Shelby
Audubon
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Jasper
Poweshiek
Iowa
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Muscatine
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Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
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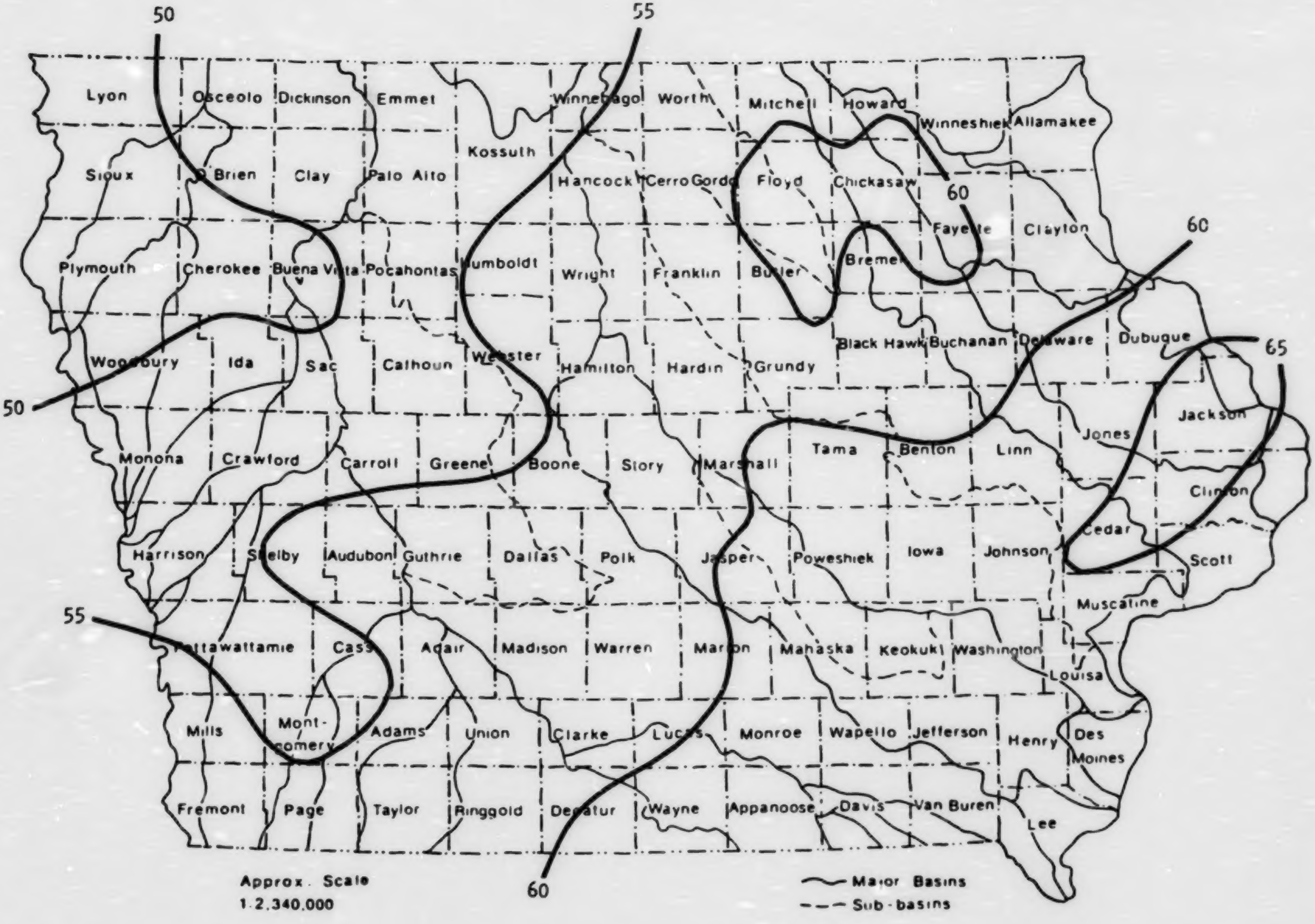
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx. Scale
1:2,340,000
Major Basins
Sub-basins

FIGURE I-14

MEAN NUMBER OF DAYS PER YEAR WITH PRECIPITATION
EQUAL TO OR GREATER THAN 0.1 INCH (4)


50
55
60
65
50
55
60
60
Lyon
Osceola
Dickinson
Emmet
Kossuth
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
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Palo Alto
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Cerro Gordo
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Chickasaw
Fayette
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Buena Vista
Pocahontas
Humboldt
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Butler
Bremer
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Poweshiek
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Pottawattamie
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Keokuk
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Lucas
Monroe
Wapello
Jefferson
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Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx. Scale
1:2,340,000
Major Basins
Sub-basins

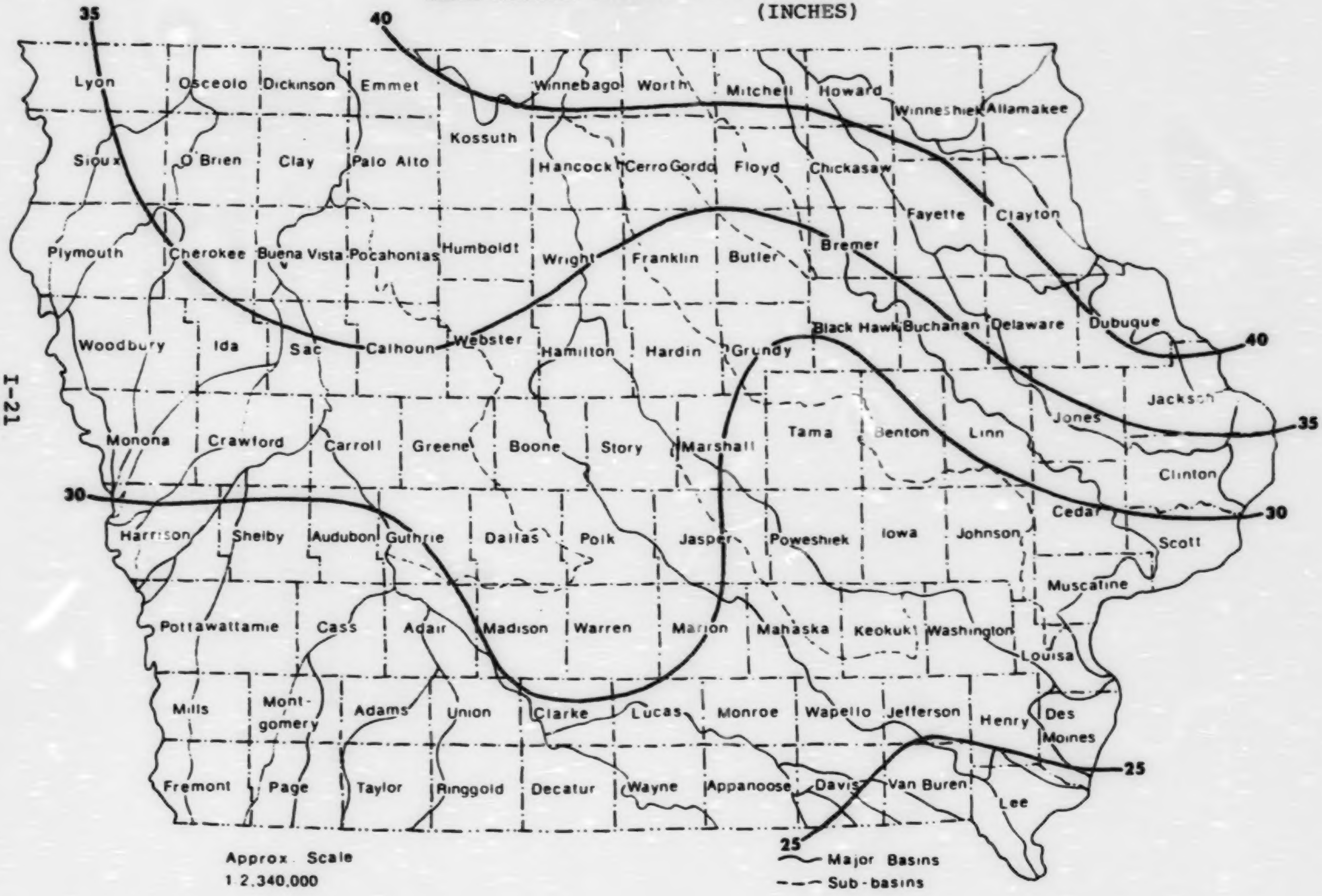
June in the afternoon and early evening. Iowa averages 8 days per year with tornados, while the average number of tornados is 15 per year. The greatest hail frequency occurs in June followed by July, May and April in that order. Damaging hail-storms, reaching a maximum in early summer, average 58 per year and destroy about 1 or 2 percent of the major crops. Severe hailstorms are slightly more frequent over northwestern counties. In any locality hail usually occurs from two to six times a year.

Drought - Drought occurs periodically in Iowa, the most severe in recent decades occurring in the 1930's. Hot dry summers were also reported in the mid-1950's, 1918, 1916, 1910, 1901, 1894, 1886 and 1975.

Floods - Floods are most frequent in June at the normal maximum rainfall period but also occur near the end of March, usually as a consequence of rain on frozen ground or rain and rapid snowmelt. Ice jams often contribute to the spring flooding.

Snowfall - Snowfall, averaging little more than 30 inches per year, has varied from a state average of 11.9 inches in 1965-66 to 59.0 inches in 1961-62. The average seasonal snowfall varies from near 20 inches at Keokuk to 35-45 inches over northern counties (Figure I-15). The season normally extends from October or November to April but measurable snow has fallen as late in the season as May

FIGURE I-15
MEAN ANNUAL SNOWFALL IN IOWA (6)
(INCHES)


35
40
40
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30
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25
25
Lyon
Osceola
Dickinson
Emmet
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Kossuth
Sioux
O'Brien
Clay
Palo Alto
Hancock
Cerro Gordo
Floyd
Chickasaw
Fayette
Clayton
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Black Hawk
Buchanan
Delaware
Dubuque
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Jackson
Jones
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Tama
Benton
Linn
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Cedar
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Scott
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Mont-gomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
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Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx. Scale
1:2,340,000
Major Basins
Sub-basins

28, (1947) and as early as September 25 (1942). The average number of days with snow cover 1 inch or deeper per season varies from about 40 days along the southern border to around 90 in the northernmost counties. The average date of the first 1-inch snowfall varies from November 25 in the north to December 10 in the southeast. The first trace of snow occurs about one month earlier. In about half the years a 24-hr. snowfall of 5 inches or more occurs over southern Iowa, 6 or more over central counties, and 7 or 8 over northern counties. Late winter snowstorms have produced as much as 31 inches of snow in a single storm and 24-hour amounts have exceeded 20 inches. The snowiest winter of record (since 1892) was 1961-62 with almost twice the seasonal average.

HYDROGEOLOGY

The information for this section is taken from the Ground Water Resources of Iowa chapter of Water Resources of Iowa (4) except where noted.

The geologic framework of Iowa's ground-water reservoir is summarized in Table I-1 and Figures I-16 and I-17. The bottom of the reservoir is the Precambrian crystalline complex, which occurs at a depth of about 5,200 feet in southwestern Iowa and rises to the surface in extreme

TABLE I-1

GEOLOGIC AND HYDROGEOLOGIC UNITS IN IOWA (4)

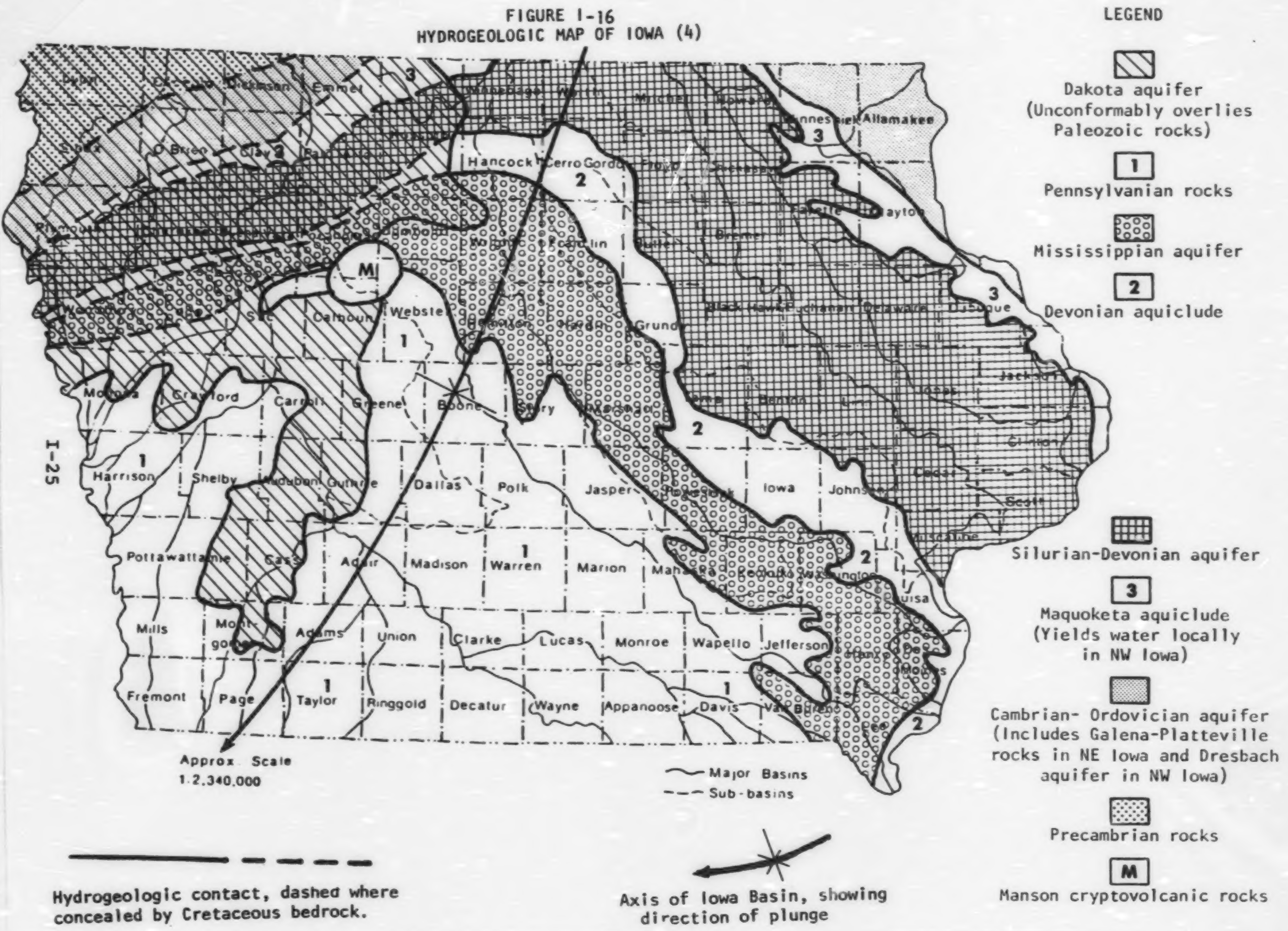
Age		Rock Unit	Description	Hydrogeologic	Water-Bearing Characteristics
Cenozoic	Quaternary	Alluvium	Sand, gravel, silt and clay	Surficial aquifer	Fair to large yields
		Glacial drift (undifferentiated)	Predominantly till containing scattered irregular bodies of sand and gravel		Low yields
		Buried channel deposits	Sand, gravel, silt and clay		Small to large yields
Mesozoic	Cretaceous	Carlile Formation; Graneros Formation	Shale	Aquiclude	Does not yield water
		Dakota Group	Sandstone and shale	Dakota aquifer	High to fair yield
Paleozoic	Pennsylvanian	Virgil Series Missouri Series	Shale and limestone	Aquiclude	Low yields only from limestone and sandstone
		Des Moines Series	Shale; sandstone, mostly thin		
	Mississippian	Meramec Series	Limestone, sandy	Mississippian aquifer	Fair to low yields
		Osage Series	Limestone and dolomite, cherty		
		Kinderhook Series	Limestone, oolitic, and dolomite, cherty		
	Devonian	Maple Mill Shale; Sheffield Formation; Lime Creek Formation	Shale; limestone in lower part	Devonian aquiclude	Does not yield water
		Cedar Valley Limestone Wapsipinicon Formation	Limestone and dolomite; contains evaporites in southern half of Iowa	Silurian-Devonian aquifer	High to fair yields
	Silurian	Niagaran Series; Alexandrian Series	Dolomite, locally cherty		

TABLE I-1 (continued)

GEOLOGIC AND HYDROGEOLOGIC UNITS IN IOWA (4)

Age		Rock Unit	Description	Hydrogeologic	Water-Bearing Characteristics
Paleozoic	Ordovician	Maquoketa Formation	Shale and dolomite	Maquoketa aquiclude	Does not yield water, except locally in northwest Iowa
		Galena Formation	Limestone and dolomite	Minor aquifer	Low yields
		Decorah Formation Platteville Formation	Limestone and thin shales; includes sandstone in SE Iowa	Aquiclude	Generally does not yield water; fair yields locally in southeast Iowa
		St. Peter Sandstone	Sandstone	Cambrian-Ordovician aquifer	Fair yields
		Prairie du Chien Formation	Dolomite, sandy and cherty		High yields
	Cambrian	Jordan Sandstone	Sandstone		
		St. Lawrence Formation	Dolomite	Aquiclude (wedges out in northwest Iowa	Does not yield water
		Franconia Sandstone	Sandstone and shale		
		Dresbach Group	Sandstone	Dresbach aquifer	High to low yields
Precambrian		Sioux Quartzite	Quartzite	Base of ground-water reservoir	Not known to yield water except at Manson cryptovolcanic area
		Undifferentiated	Coarse sandstones; crystalline rocks		

FIGURE I-16
HYDROGEOLOGIC MAP OF IOWA (4)


LEGEND
▨ Dakota aquifer (Unconformably overlies Paleozoic rocks)
1 Pennsylvanian rocks
Mississippian aquifer
2 Devonian aquiclude
▦ Silurian-Devonian aquifer
3 Maquoketa aquiclude (Yields water locally in NW Iowa)
Cambrian- Ordovician aquifer (Includes Galena-Platteville rocks in NE Iowa and Dresbach aquifer in NW Iowa)
Precambrian rocks
M Manson cryptovolcanic rocks
Hydrogeologic contact, dashed where concealed by Cretaceous bedrock.
Axis of Iowa Basin, showing direction of plunge
Major Basins
Sub-basins
Approx. Scale 1.2,340,000
Dickinson
Emmet
O Brien
Clay
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Hancock
Cerro Gordo
Floyd
Clayton
Franklin
Butler
Bremer
Black Hawk
Buchanan
Delaware
Dubuque
Webster
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Shelby
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Warren
Marion
Mahaska
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Louisa
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Montgomery
Adams
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Clarke
Lucas
Monroe
Wapello
Jefferson
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Des Moines
Fremont
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Taylor
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Decatur
Wayne
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Davis
Van Buren
Lee
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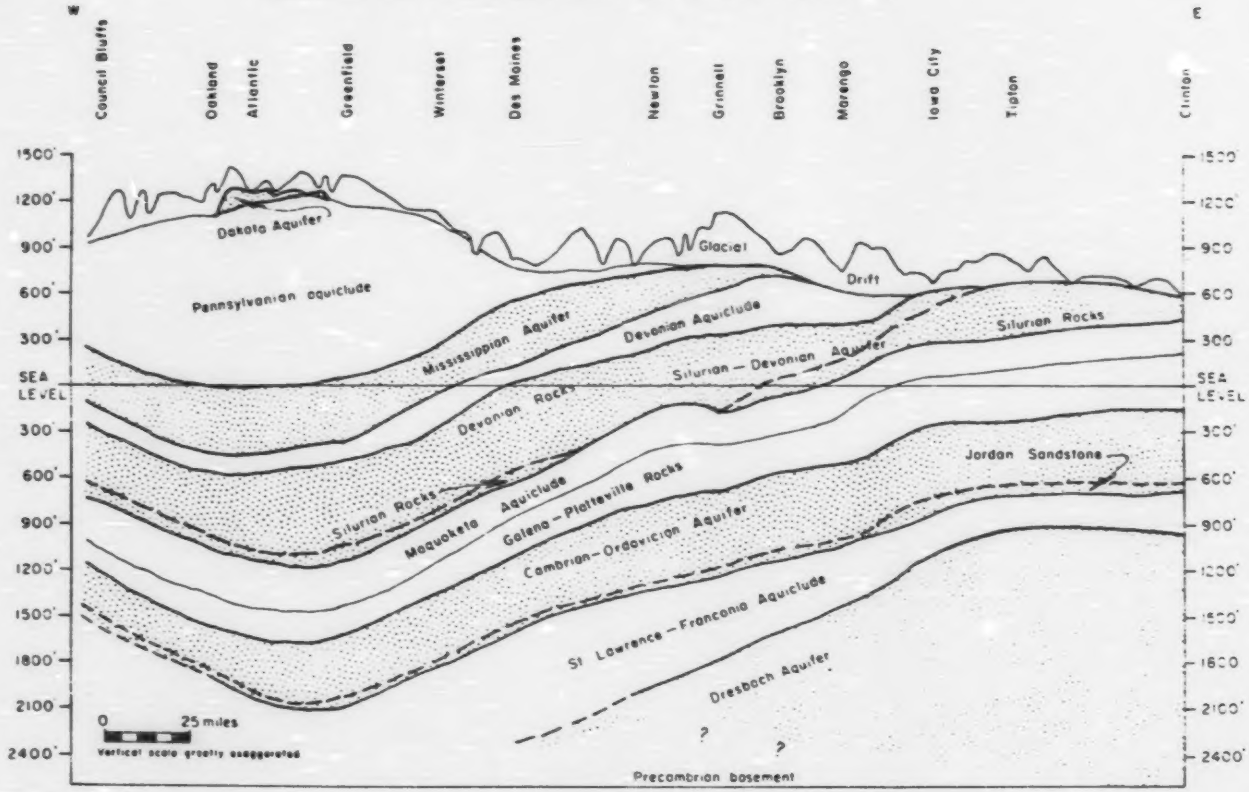
3
M

FIGURE I-17
GENERALIZED HYDROGEOLOGIC SECTION OF IOWA (4)


W
E
Council Bluffs
Oakland
Atlantic
Greenfield
Winterset
Des Moines
Newton
Grinnell
Brooklyn
Marengo
Iowa City
Tipton
Clinton
1500'
1200'
900'
600'
300'
SEA LEVEL
300'
600'
900'
1200'
1500'
1800'
2100'
2400'
Dakota Aquifer
Pennsylvanian aquiclude
Glacier
Drift
Mississippian Aquifer
Devonian Aquiclude
Silurian Rocks
Silurian – Devonian Aquifer
Devonian Rocks
Jordan Sandstone
Silurian Rocks
Maquoketa Aquiclude
Galena – Platteville Rocks
Cambrian – Ordovician Aquifer
St Lawrence – Franconia Aquiclude
Dresbach Aquifer
?
?
Precambrian basement
0
25 miles
Vertical scale greatly exaggerated

northwestern Iowa and to within 800 feet of the surface in northeastern Iowa. Overlying this complex is a succession of consolidated sedimentary strata of Paleozoic Age that are dominantly sandstones and dolomites in the lower part, and shales, dolomites, and limestones in the upper part. These strata have been downwarped into a broad trough, known as the Iowa Basin (Figures I-16 and I-17). The surface of the dipping Paleozoic rocks was leveled by erosion, thus exposing older Paleozoic strata in the northeastern and northwestern parts of the State and forming the extensive recharge areas of the Paleozoic aquifers in northeastern Iowa and southern Minnesota.

Strata of Cretaceous Age uncomfortably overlie the leveled, southeast-dipping limb of the Paleozoic basin in northwestern and parts of southwestern Iowa (Figures I-16 and I-17). These nearly flat-lying strata are dominantly shales and sandstones that attain a thickness of as much as 400 feet.

Of the principal aquifers, the highly productive ones can be divided into two categories on the basis of their recharge and water-yielding characteristics. In one category are the highly productive alluvial and shallow carbonate-rock aquifers directly underlying and in hydrologic connection with principal streams. These aquifers have a close space-time relationship to the streams so that, under certain conditions, most of the water withdrawn from these aquifers is induced surface water.

In the other category are the deep, highly productive artesian aquifers in Iowa that are a considerable distance from recharge sources. These deeply buried aquifers act as conduits carrying water from outcrop areas miles or hundreds of miles to the areas of natural or artificial discharge. This movement, is extremely slow for the deep formations. The quantity of water available from storage in these aquifers, however, is so great that large withdrawals are possible without critically depleting the supply. Development is often limited locally by the excessive costs of increased pumping lift. These aquifers can help to support base flow at centers of ground-water withdrawal. This can be significant during low-flow periods.

Interstratified with the bedrock aquifers are a number of non-water-yielding shales and dense unfissured carbonate rocks of great areal extent (Table I-1 and Figures I-16 and I-17). These are the regional aquicludes that confined ground-water flow to the aquifers by retarding vertical movement of water in the reservoir. The nature and depth of the aquifers in any locality thus depend on the local geology, and this may differ appreciably even within short distances.

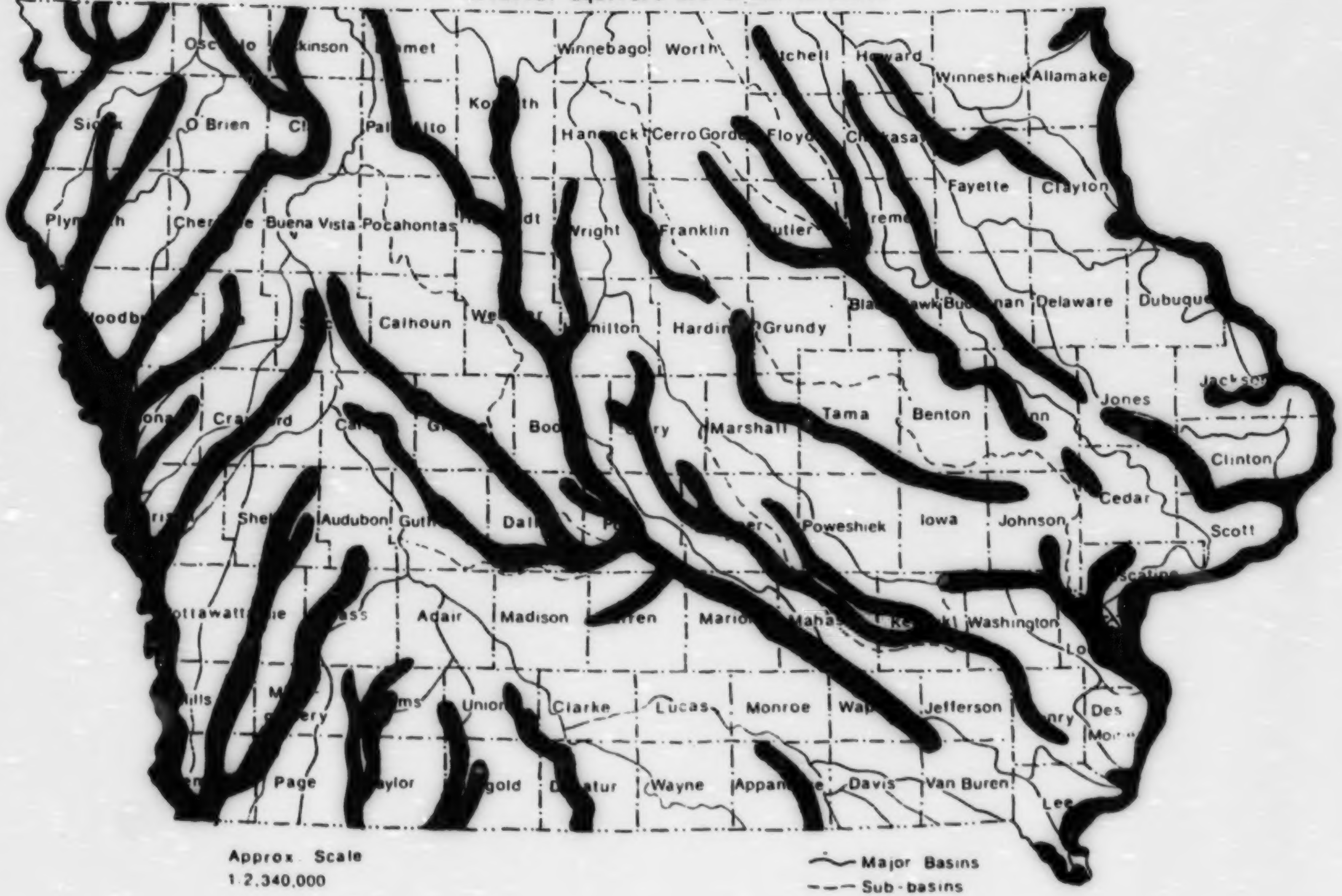
Surficial Aquifers

The surficial aquifers of Iowa comprise fluvio-glacial outwash deposits and fluvial deposits of Quarternary Age (called alluvial deposits or alluvium) found along the present watercourses, outwash sands occupying buried bedrock channels, and thin discontinuous sand bodies in glacial drift. The alluvial and buried valley deposits are important sources of moderate to large water supplies but are restricted in occurrence to river valleys and preglacial drainage lines. The glacial drift is a source of small supplies only, but is important as a source of rural supplies because of its widespread occurrence.

Alluvial deposits underlying the flood plains and terraces of Iowa's principal rivers constitute productive aquifers that are currently and potentially important sources of water (Figure I-18). These reservoirs are relatively small, but they have large storage characteristics and are recharged normally at rather frequent intervals. Recharge occurs from local precipitation and seepage from adjacent streams where withdrawals are large. Therefore, they are dependent on surface water quality and quantity.

Some of the unconsolidated sediments are very productive and are major sources of water supply at several localities. Because of their near-surface locations, mostly near rivers, they can be economically developed

FIGURE I-18
ALLUVIAL AQUIFERS OF IOWA (4)
Alluvial aquifers are shown in dark.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Buena Vista
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Des Moines
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Wayne
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Van Buren
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Approx Scale
1:2,340,000
Major Basins
Sub-basins

with relatively shallow wells and low pumping lifts, and are dependable sources of supply. These deposits are used widely for stock and domestic supplies. The largest single municipal supply in Iowa, at Des Moines, is obtained from sand and gravel along the Raccoon River.

Glacial drift is a source of water supply for numerous farms and rural homesteads throughout the state, except in the extreme northeast corner where the drift is largely absent. The drift consists principally of pebbly and sandy boulder clay containing lenticular or shoestring bodies of sorted sand and some poorly sorted sand and gravel. The drift thickness ranges from zero to 600 feet and averages about 200 feet. The producing zones are the sand bodies within or at the base of the drift. Wells may range from 15 to 20 feet to as deep as 400 feet or more. Generally, these wells yield only a few gallons per minute, but with favorable conditions and proper well design as much as 10 to 20 gpm may be obtained.

Bedrock Aquifers

The six principal water-yielding rock units in the Iowa reservoir are the surficial deposits, the Dakota Sandstone of Cretaceous Age, limestones and dolomites of Mississippian Age, limestones and dolomites of Silurian and Devonian Age, the Cambrian and Ordovician sandstones and dolomites, and the Dresbach sandstones of Cambrian Age. (Table I-1). The most consistently productive units are the Cambrian and Ordovician sandstones and dolomites. Others that are highly productive locally are the alluvium (surficial deposits), the Dresbach and Cretaceous sandstones, and limestones or dolomites of Silurian, Devonian, or Mississippian Age where they directly underlie major streams.

Dakota Sandstone - Strata of Cretaceous Age, principally the Dakota Sandstone (Table I-1), comprise the chief bedrock aquifer in northwestern Iowa and less extensively in western and southwestern part of the state as far east as Kossuth, Wright, Webster, Greene, and Guthrie Counties, and as irregular remnants as far south as Montgomery and Page Counties (Figure I-16). Maximum thickness of the full Cretaceous System is somewhat more than 400 feet in central Sioux and Osceola Counties, from where it thins northwestward and southeastward.

Deposits of sandy and pebbly glacial drift of variable thickness mantles the Cretaceous rocks. Generally in the northwestern counties the Dakota aquifer is reached at depths between 250 and 600 feet whereas in the eastern areas it is reached at between 100 and 350 feet.

Usually the Dakota Sandstone is rather fine-grained and poorly cemented, which frequently causes sand-pumping troubles when wells are over-pumped. Proper well construction and aquifer development can minimize this problem.

Yields from the sandstone aquifer are somewhat erratic and unpredictable, varying from a few tens to a few hundred gallons per minute. The aquifer generally can be counted on to produce sufficient water for all rural and many municipal requirements. Even where the aquifer is only moderately thick, many wells have been developed to yield 50 to 100 gpm.

Mississippian Aquifer - The Mississippian aquifer consists of a thick sequence of limestones and dolomites between the overlying shales of Pennsylvanian Age and the underlying Maple Mill-Sheffield shales of Devonian Age (Table I-1). These rocks underlie that part of Iowa south of a line from Des Moines County northwestward to Hancock County and thence southwestward to Woodbury County (Figure I-16).

The aquifer thickness ranges from zero to about 600 feet with the average thickness about 350 feet. In the area where the aquifer has its main development, the average thickness probably is closer to 250 feet. In certain locations preglacial streams cut deep channels into the bedrock and removed much of the upper part of the Mississippian rocks.

The principal area for developing wells in the Mississippian aquifer is an elongated belt roughly bounded by a line extending from Des Moines County to Wright County on the northeast and by the Des Moines River on the southwest. This includes the subcrop area of the aquifer and an irregular fringe area of thin overlapping Pennsylvanian rocks immediately southwest of the subcrop area (Figures I-16 and I-17). In the north central part of this area the specific capacity of wells completed in the Mississippian aquifer generally is more than 1.0 gpm per ft. of drawdown and yields of 100 to 200 gpm are common. Less favorable conditions are found in the central and southeastern parts of the area.

In this principal development belt, the Mississippian aquifer is overlain by glacial drift and in places by Pennsylvanian shale and usually lies 50 to 100 feet below the surface in the north-central part of the area and 100 to 400 feet below the surface in the central and southeastern parts. The aquifer has a gradual overall dip to the southwest from the main subcrop area, so that many hundreds of feet of Pennsylvanian rocks and glacial clays overlie the aquifer in south-central and southwestern Iowa (Figure I-17). The water is of such poor quality however, that the aquifer is little used.

Silurian-Devonian - The Silurian Devonian aquifer, comprising the Niagran and Alexandrian Series of Silurian Age and the Cedar Valley and Wapsipinicon Formations of Devonian Age (Table I-1), underlies the entire State for the northeastern and northwestern corners. The aquifer subcrops immediately beneath the glacial drift in a broad belt in northeastern Iowa and beneath the Cretaceous rocks in a narrow belt in northwestern Iowa (Figure I-16). Southwest and southeast of these subcrop areas, it dips beneath the Devonian aquiclude and other younger Paleozoic rocks (Figure I-17). The aquifer's thickness ranges from zero to 650 feet and generally is between 200 and 350 feet throughout its area of occurrence.

In the northeastern subcrop area, where the aquifer is overlain only by glacial drift, the depth to the top of the aquifer ranges from zero to about 300 feet, the greater depths generally along the southwestern part of the subcrop area. Elsewhere the aquifer is reached only after drilling though several hundreds of feet of younger consolidated rocks and glacial drift (Figure I-17).

The aquifer is composed of relatively dense limestone and dolomite, whose porosity and permeability are dependent principally on secondary rock openings---fractures, joints, bracciated zones, and solution tubules. The anisotropic nature of the aquifer makes it difficult to predict yields with any assurance. The aquifer's porosity and permeability are known to be best developed in the northeast subcrop area. In this area, the aquifer is overlain by glacial drift and receives recharge more readily than it does in the area where the aquifer is covered by the Devonian aquiclude. Many municipal and industrial wells obtain between 150 and 400 gpm per well from the aquifer. Most domestic wells pumping from the Silurian-Devonian aquifer will deliver from 10 to 30 gpm with small to moderate drawdowns.

The Silurian-Devonian aquifer is utilized much less in the area where it is overlain by the Devonian aquiclude. In the central and southern parts of the state, yields of 20 to 150 gpm can be obtained, but the water contains high concentrations of sulfate and total dissolved solids. The mineralization is attributed to thick evaporite deposits, gypsum and anhydrite, that occur in the Cedar Valley and Wapsipinicon formations.

Cambrian-Ordovician Aquifer - The Cambrian-Ordovician aquifer is widespread and consistently yields several hundred to more than 1,000 gpm to individual wells throughout the eastern three-fourths of the state. It crops out in the northeastern corner of the state and subcrops beneath the Cretaceous rocks in northwestern Iowa (Figure I-16). The aquifer is present beneath younger Paleozoic rocks at progressively greater depths to the southwest and southeast. Owing to the dip of the Cambrian-Ordovician aquifer toward the southwest in Iowa, the depth of wells necessary to penetrate it increases from about 700 feet in northeastern Iowa to about 2,000 feet southwest of Des Moines to about 3,200 feet in southwestern Iowa. Artesian pressure in the aquifer is usually sufficient to raise the water levels in wells to within 300 feet of the land surface. In many areas the wells flow at the surface.

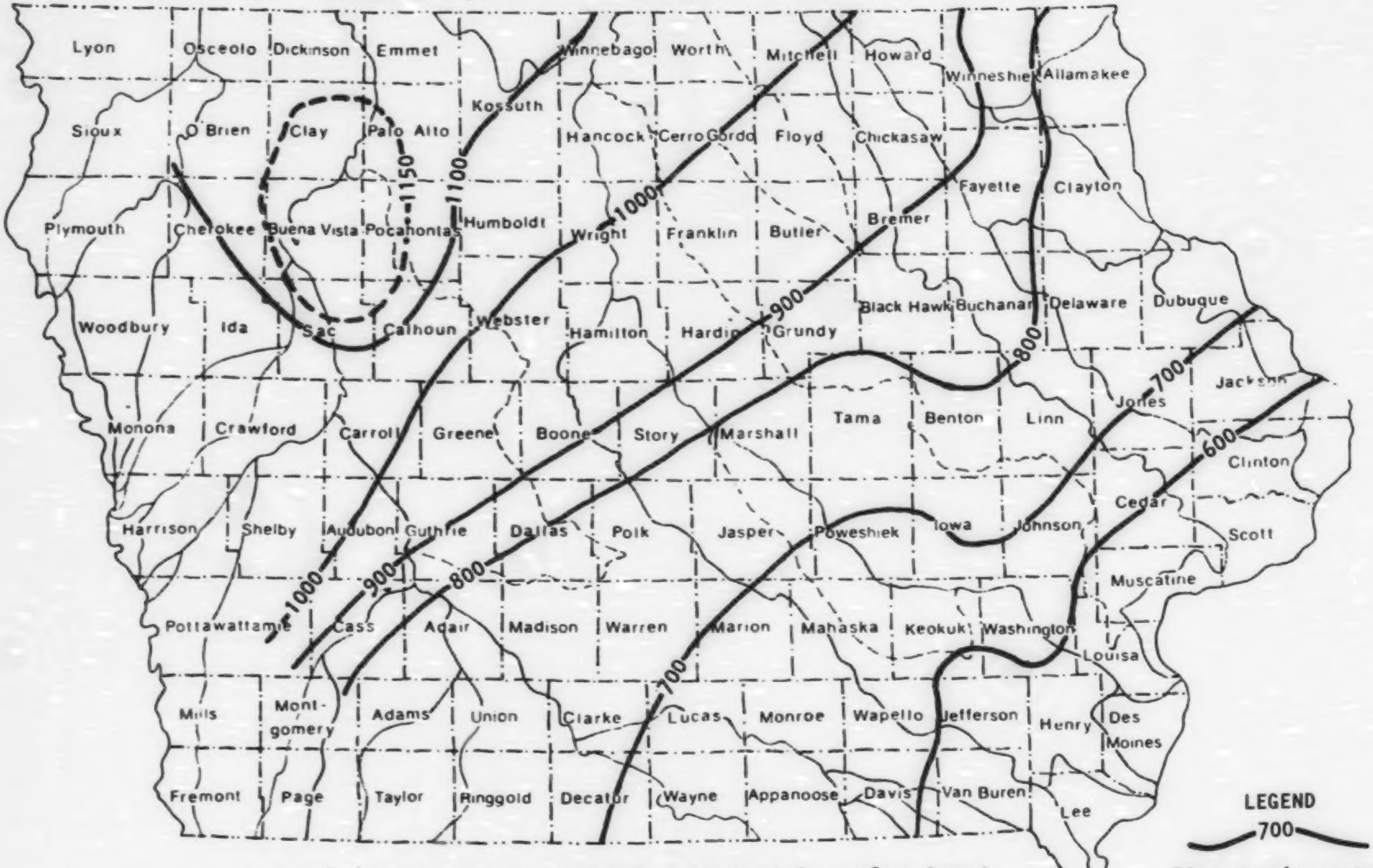
The total thickness of the water-bearing unit ranges from 0 to 600 feet in eastern Iowa and from 0 to 400 feet in the western part of the State the average thickness throughout its subsurface extent is generally between 400 and 500 feet.

The aquifer consists of three water-bearing formations, the St. Peter Sandstone and Prairie du Chien Formation of Ordovician Age and the Jordan Sandstone of Cambrian Age (Table I-1). The St. Peter is a friable, medium-grained, almost pure quartzose sandstone that is rarely more than 50 feet thick. Although it is capable of yielding 50 gpm or more to wells in eastern Iowa, the formation generally is cased off in wells drilled to the Cambrian-Ordovician aquifer to prevent caving of the friable sandstone or to shut off poor-quality water. The Prairie du Chien Formation consists principally of dolomite but includes some sandstone beds. Its thickness is several hundred feet in the subsurface of eastern and southern Iowa, but in northwestern Iowa the formation wedges out. The formation is believed to yield significant amounts of water to wells penetrating the Cambrian-Ordovician aquifer; however, its performance generally is masked by the performance of the underlying Jordan Sandstone. The Prairie du Chien is the principal water-producing unit for some wells in south-central Iowa. Also, in some unusually high capacity wells (greater than 25 gpm per ft. of drawdown) finished in the Cambrian-Ordovician aquifer, most of the water is obtained from extensive crevices in the Prairie du Chien. The Jordan sandstone is the principal water-producing unit and is penetrated by practically all wells drilled to the Cambrian-Ordovician aquifer. This formation is a medium-to-coarse-grained, pure quartzose sandstone whose thickness ranges from 75 to 125 feet in southwestern Iowa.

Recharge to this deep artesian aquifer in Iowa is principally by subsurface inflow from the north, and discharge is by subsurface outflow to the southeast (Figures I-19). The average velocity of flow through the aquifer, from recharge to discharge area, is calculated to be about 100 feet per year.

The aquifer is used extensively by municipalities and industries in the eastern three-fourths of the State. Many small communities in central and southern Iowa also use the aquifer because the overlying rocks do not yield enough water or the water is highly mineralized. Yields of up to 1,000 gpm are obtainable in most of the northeastern one-half of the State. Limited well data indicate that yields of only 100 to 300 gpm are available in much of the southwestern quarter of the State. Specific capacities of wells finished in the aquifer commonly range from 5 to 25 gpm per ft. of drawdown in northern and eastern Iowa and from 1 to 3 gpm per ft. of drawdown in southwestern Iowa. Occasional specific capacities of 30 to 80 gpm per ft. of drawdown have been reported from the eastern half of the State. The yields and specific capacities of many wells have been increased 50 to 100 percent by acidizing or shooting and surging the wells.

FIGURE I-19
PIEZOMETRIC MAP OF CAMBRIAN-ORDOVICIAN AQUIFER (4)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Bremer
Woodbury
Ida
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Webster
Hamilton
Hardin
Grundy
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Delaware
Dubuque
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Carroll
Greene
Boone
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Marshall
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Louisa
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Mont-gomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
1150
1100
1000
900
800
700
600
LEGEND
700
Piezometric contour
Approx Scale
1 2.340.000

Shows altitude of pre-development piezometric surface based on original water-level information. Contour interval 100 feet. Supplemental 50 foot contour shown by dashed line. Datum is sea level.

Most properly developed or stimulated wells in eastern and northern Iowa will yield over 1,000 gpm and have specific capacities of 10 gpm per ft. or more.

Significant lowering of the aquifer's pressure head has occurred at a number of localities where large amounts of water are pumped from the aquifer. Loss of pressure head in the vicinity of wells pumping from the aquifer have been recorded at Ottumwa (100 feet in 70 years), and a number of other smaller communities in southeastern Iowa.

Dresbach Aquifer - The Dresbach aquifer as here defined consists of a sequence of coarse-to fine-grained sandstones between the overlying Franconia Formation of Cambrian Age and the underlying crystalline rocks or quartzites of Precambrian Age (Table I-1). The group is divided into three formations from the top down--the Galesville sandstone, Eau Claire formation, and Mount Simon sandstone. The combined Ironton-Galesville section is about 150-200 feet thick in eastern Iowa, but thins westward and appears to be absent in the western half of the State. The Eau Claire is principally a fine-grained sandstone in the eastern counties, but changes to a shale in central Iowa; locally it contains dolomite. This unit's thickness averages about 200 feet. The Mount Simon is practically all sandstone although some thin shales may be present in the lower part. The Mount Simon sandstones are about 1,325 feet thick at Clinton, at least 325 feet thick at State Center, and 125 feet thick at Redfield.

The top of the Dresbach lies at a depth of 50 to 75 feet below the surface in the northeastern corner of the State and dips gradually to the south and southwest. It was reached at 675 feet at Dubuque, 1,600 feet at Clinton, 2,030 feet at Burlington, 2,980 feet at State Center, and 3,560 feet in Page County in southwestern Iowa.

The Dresbach is a significant aquifer only in a few eastern counties, where it is also one of the most productive in Iowa. Some wells in the area are capable of delivering 2000 to 3000 gpm with specific capacities of from ten to as high as 100 gpm per foot of drawdown.

Manson Area

The Manson area shown on some maps represents a cryptovolcanic area where crystalline Precambrian rocks occur near the land surface. Except for isolated patches, these crystalline rocks are not covered by any bedrock aquifers.

GROUND WATER QUALITY

The information for this section is taken from "The Chemical Quality of Iowa's Water Resources" chapter of Water Resources of Iowa (4) except where noted.

Nearly all of Iowa's ground waters are very hard. Hardnesses range from 250 to 500 mg/l for ground waters from the more commonly used aquifers. Some alluvial aquifers will yield water with a hardness of from 150 to 200 mg/l, and water from some bedrock aquifers in areas where they yield highly mineralized water often will have a hardness in excess of 1,000 mg/l. These waters usually grade from calcium or calcium magnesium to the sodium type and from bicarbonate to sulfate or chloride type in areas where the dissolved-solids content increases. The mineral content of the groundwater, described by total dissolved solids and hardness, generally increases with increasing depth.

Iron occurs in amounts (more than 0.3 mg/l) which can cause problems in some places in all aquifers. Iron in troublesome amounts is commonly found in water from the alluvial aquifers, in sand aquifers beneath the glacial drift, and in near-surface bedrock aquifers.

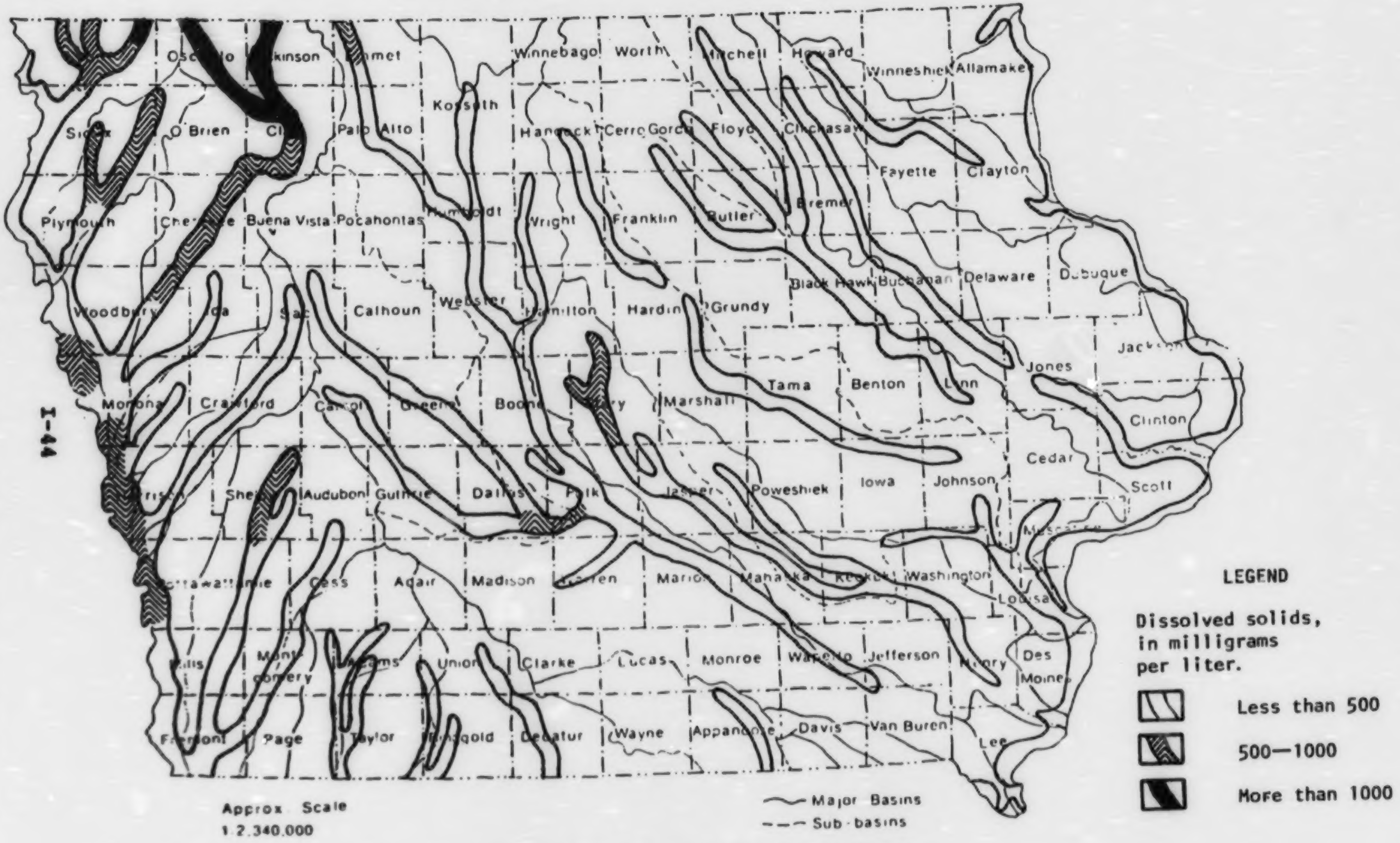
Nitrates in excess of acceptable concentrations have been found in many shallow wells. More than 45 mg/l of nitrates are thought to cause methemoglobinemia in infants.

The occurrence of high nitrate concentrations is related more to improper well construction and location than to a particular region. Instances of properly constructed wells yielding high nitrate concentrations are, however, common in some alluvial aquifers. Upper layers of sand and gravel may contain unacceptable amounts whereas parts of the aquifer below an intervening clay layer contain negligible amounts of nitrate. Continued applications of fertilizer on flood plain and terrace areas may result in this problem becoming more widespread. Where clay layers do not separate the alluvial aquifers into two or more parts, nitrates may contaminate the only major source of groundwater over a large area.

Alluvial Aquifers

Alluvial aquifers offer a source of good-to-fair quality water in many areas where the underlying bedrock aquifers contain mineralized water. The quality of the water from the alluvial aquifers is quite variable. The quality depends a great deal on the thickness of the aquifer, the depths of the wells, the underlying aquifer or aquiclude, and whether the water is coming from storage, induced infiltration, or from local precipitation. The climatic conditions often have much to do with the quality.

Generally water containing less than 500 mg/l of dissolved solids can be found in the alluvial aquifers (Figure I-20). The only areas having dissolved solids generally greater than 1000 mg/l are in the northwest along the Little Sioux and the Rock Rivers. All alluvial waters in Iowa are of the calcium bicarbonate or calcium magnesium bicarbonate type except in the reaches where the dissolved-solids concentrations are more than 1,000 mg/l. These waters are of the calcium sulfate type.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Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Approx. Scale
1:2,340,000
Major Basins
Sub-basins
LEGEND
Dissolved solids, in milligrams per liter.
Less than 500
500—1000
More than 1000

FIGURE 1-20 DISSOLVED SOLIDS CONCENTRATIONS OF THE WATER FROM THE ALLUVIAL AQUIFERS (4)

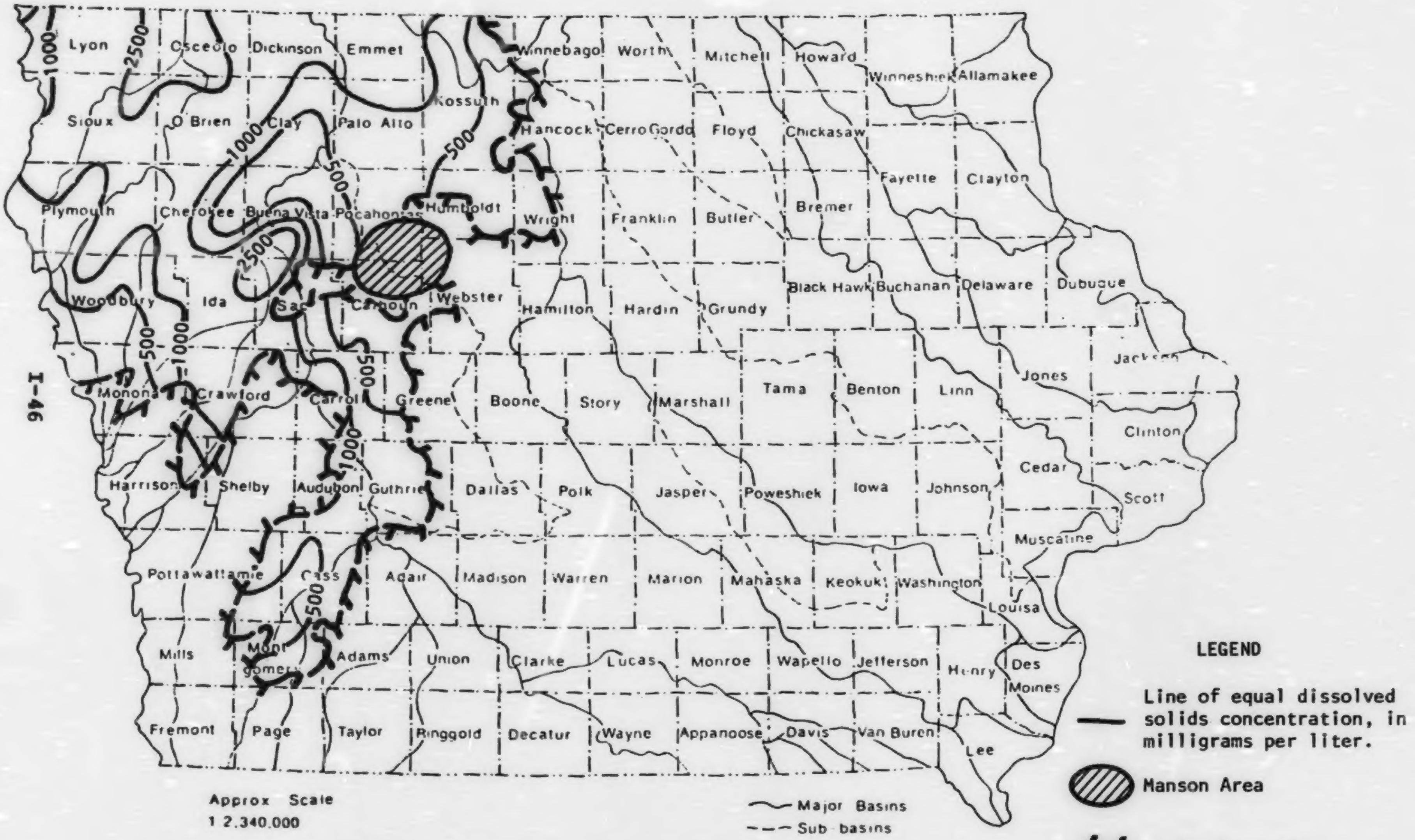
Bedrock Aquifers

The major aquifers in Iowa are the Dakota sandstone, Mississippian limestones and dolomites, Silurian-Devonian limestones and dolomites, and the Jordan sandstone and associated dolomites.

The water quality in the bedrock aquifers is shown on the following pages by a series of maps showing the distribution of the dissolved solids. The highest dissolved-solids value shown on the map is 2,500 mg/l. Concentrations can greatly exceed this value in some places, but it is not practical to show these areas on generalized maps. Areas of unusually high concentrations are mentioned in the following text.

Dakota Sandstone - The Dakota sandstone of Cretaceous Age covers more than 20 percent of the state, but its dissolved-solids concentration is below 500 mg/l in less than 5 percent of Iowa and below 1,000 mg/l in about 12 percent. Figure I-21 represents water from the upper part of the Dakota sandstone. Waters with concentrations greater than those shown on the map are sometimes encountered. The highest concentrations of dissolved solids occur in the west-central and north-western areas.

Mississippian Aquifer - The Mississippian aquifer underlies about 60 percent of Iowa and is an important source of water to several communities in about 10 percent of the State. It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Fremont
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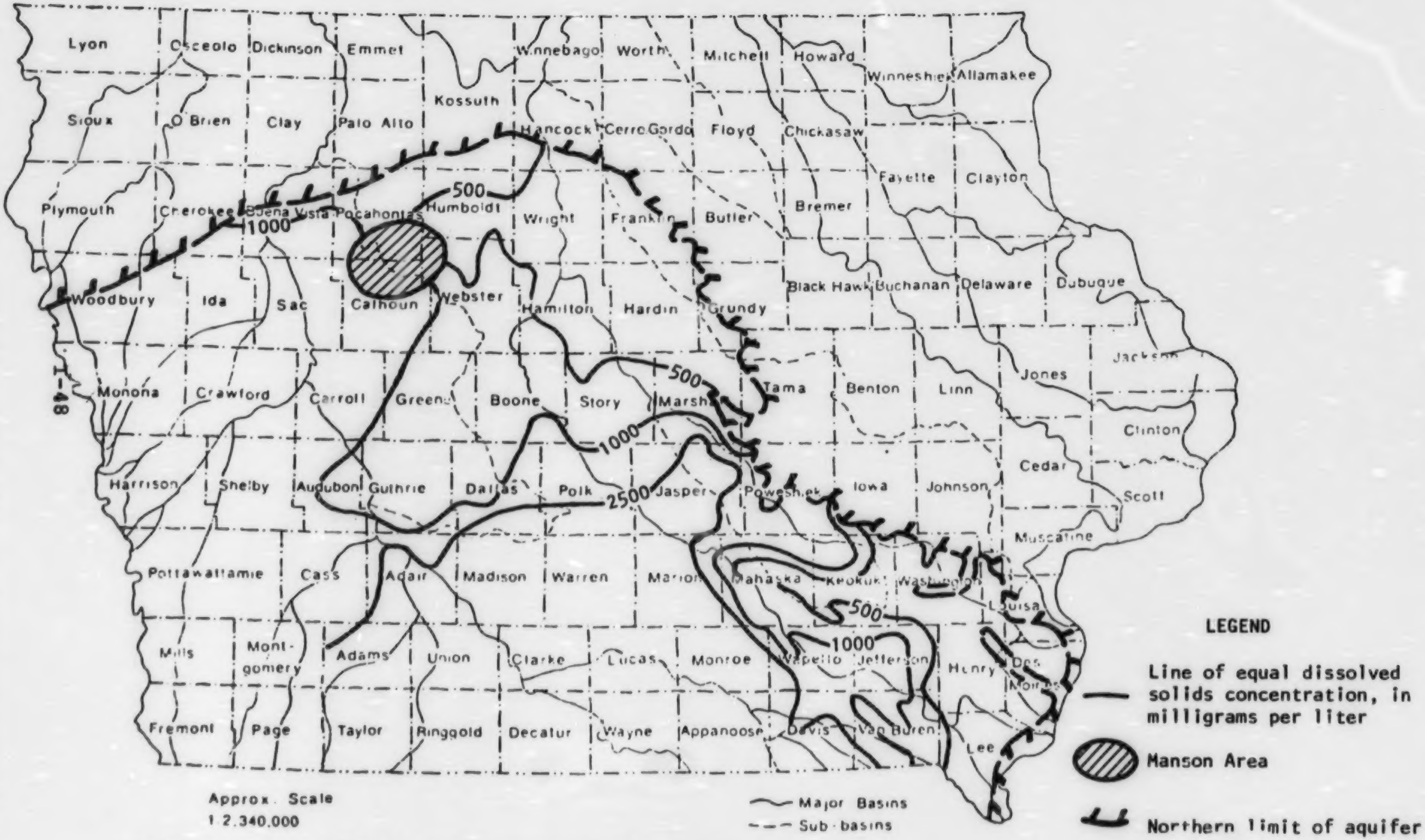
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
1000
2500
500
1000
2500
500
1000
500
1000
500
LEGEND
Line of equal dissolved solids concentration, in milligrams per liter.
Manson Area
Limit of aquifer
Major Basins
Sub basins
Approx Scale
1 2.340.000

FIGURE 1-21 DISSOLVED SOLIDS CONCENTRATIONS OF WATER FROM THE DAKOTA AQUIFER (4)

consistently provides water of good quality in the north central part of the State and somewhat less consistently in the southeast (Figure I-22). The 2,500 mg/l line outlines the area where evaporite deposits are often found in the Mississippian rocks. In southern Iowa dissolved-solids concentrations of greater than 3,000 to 4,000 mg/l are common and concentrations of up to 8,000 mg/l are not unusual. The Mississippian is one aquifer that yields some water containing excessive amounts of fluoride. This occurs in parts of Boone, Dallas, Polk, and Story Counties in central Iowa.

Silurian-Devonian Aquifer - The Silurian-Devonian aquifer occurs in about 85 percent of Iowa. It is an important source of water over the northeastern quarter of the State where the dissolved-solids content generally is less than 500 mg/l (Figure I-23). The dissolved-solids content of the water increases rapidly in a southward direction mainly because of the presence of evaporite minerals, mostly gypsum and anhydrite, which are present in the Devonian rocks. The area of evaporite occurrence in the Devonian is generally that enclosed by the 2,500 mg/l line on the map. The dissolved-solids content of the water from the Silurian-Devonian aquifer in the evaporite may exceed 8,000 mg/l, especially in southeastern Iowa.

Jordan Aquifer - The most productive bedrock aquifer in Iowa is the Jordan aquifer. It is found in nearly the entire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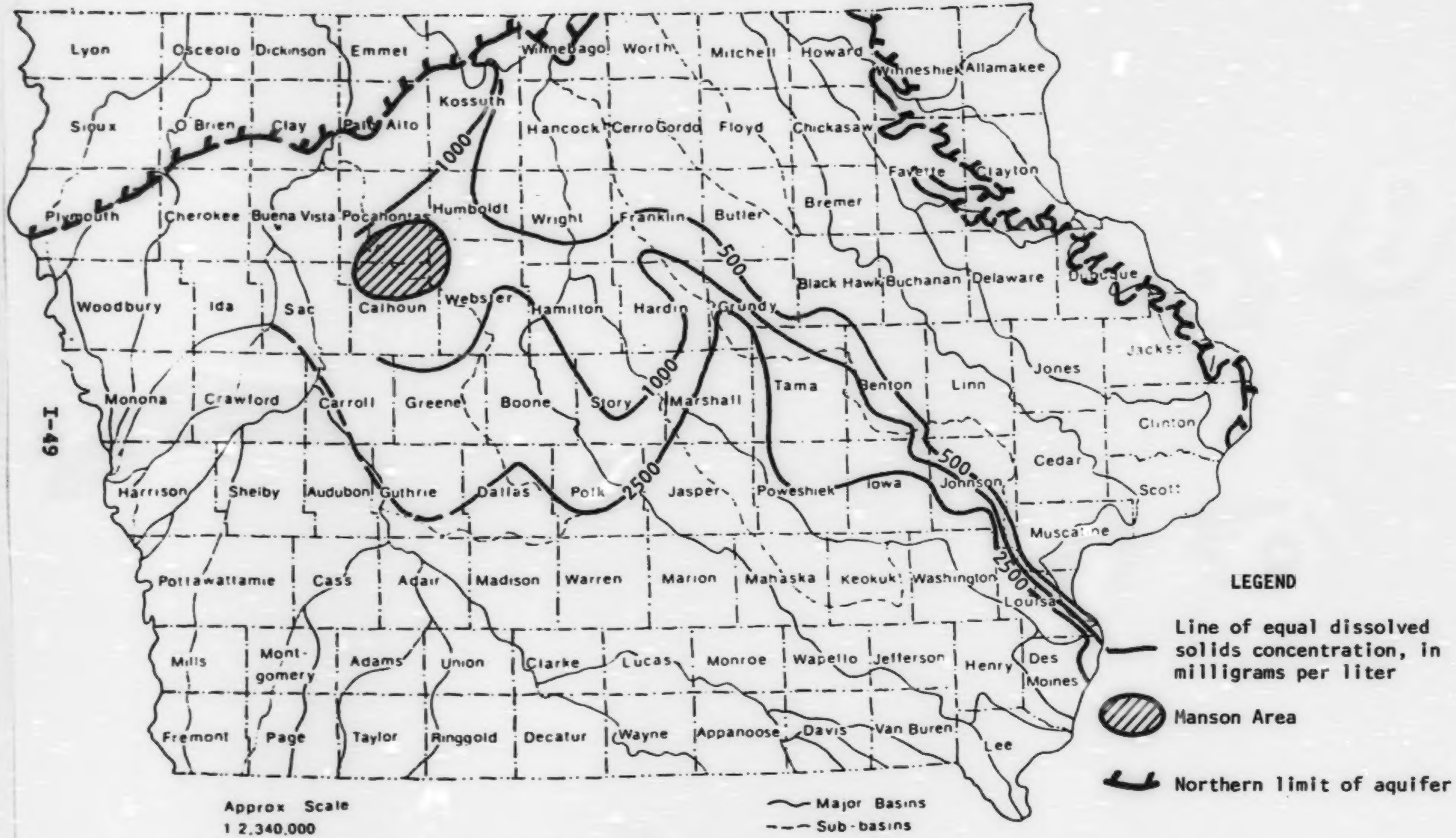
Davis
Van Buren
Lee
500
1000
500
1000
2500
500
1000
Approx. Scale
1:2,340,000
Major Basins
Sub-basins
LEGEND
Line of equal dissolved solids concentration, in milligrams per liter
Manson Area
Northern limit of aquifer

FIGURE 1-22 DISSOLVED SOLIDS CONCENTRATIONS OF WATER FROM THE MISSISSIPPIAN AQUIFER (4)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Bremer
Woodbury
Ida
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Calhoun
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Grundy
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Dubuque
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Marshall
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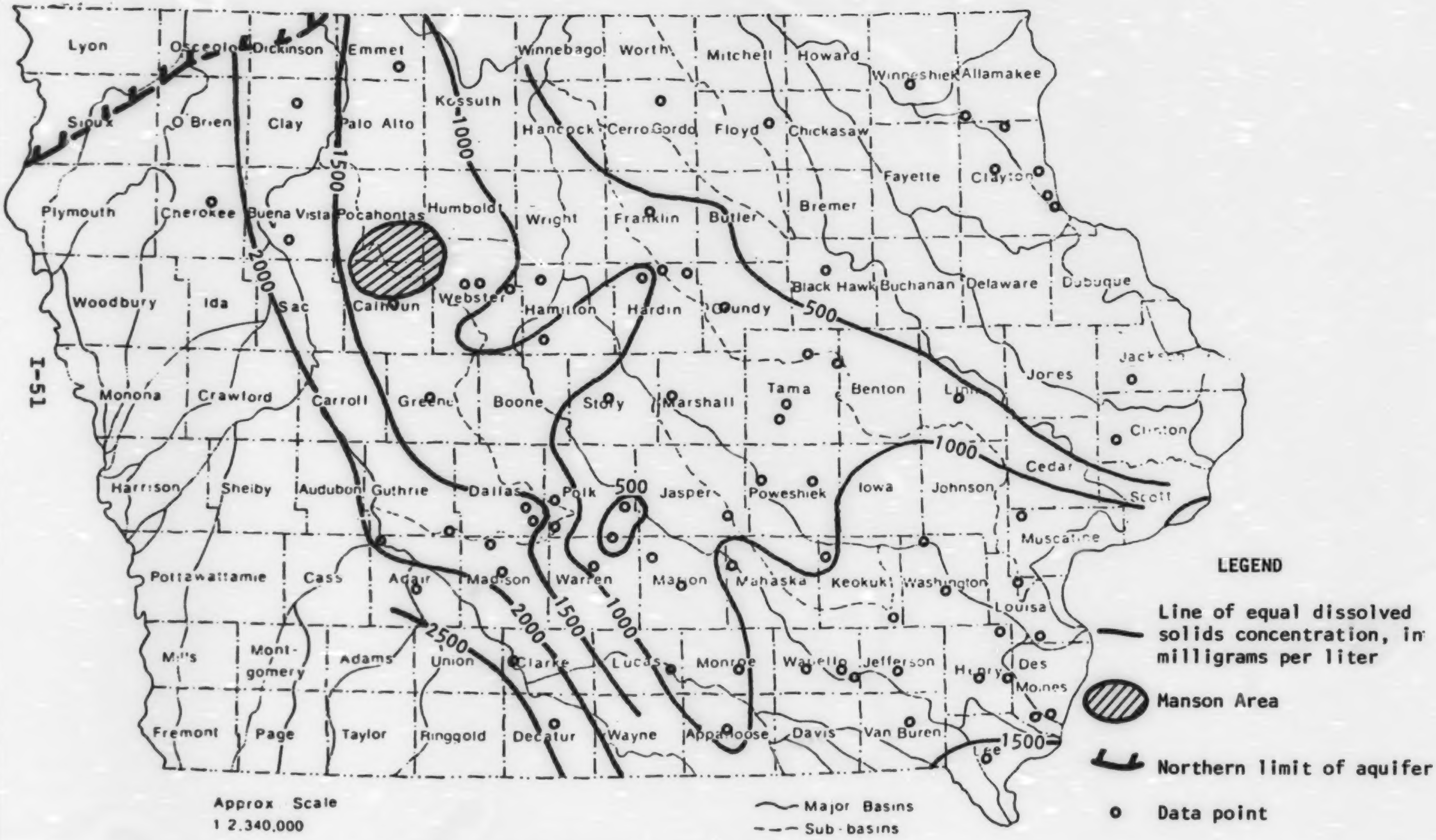
Benton
Linn
Jones
Jackson
Clinton
Harrison
Shelby
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Cedar
Scott
Muscatine
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
1000
500
1000
2500
500
2500
Approx Scale
1 2,340,000
Major Basins
Sub-basins
LEGEND
Line of equal dissolved solids concentration, in milligrams per liter
Manson Area
Northern limit of aquifer

FIGURE 1-23 DISSOLVED SOLIDS CONCENTRATIONS OF WATER FROM THE SILURIAN-DEVONIAN AQUIFER (4)

State and is used extensively in the eastern two-thirds of Iowa. The dissolved-solids concentration is often less than 300 mg/l in the northeast and increases toward the west and south (Figure I-24). Water with less than 500 mg/l of dissolved solids is found in the Jordan aquifer over more than 20 percent of the State, less than 1,000 mg/l in more than 35 percent, and less than 1,500 mg/l in over 60 percent of the State. Analyses from the Jordan aquifer also show fluoride in excessive amounts in an area west of the city of Des Moines and southwest of the Des Moines River downstream from the city. Several Jordan wells there yield more than 2.0 mg/l of fluoride, and some have amounts slightly more than 3.0 mg/l.

A comparison of Figures I-22 and I-23 with Figure I-24 will reveal why the Jordan is an important aquifer in Iowa. In a large area, the Jordan contains water with lower concentrations of dissolved solids than is contained in the bedrock aquifers which overlie it. This fortunate situation affords a potable supply to many communities and industries where other sources of water are unsuitable.

A problem does exist in these areas, however, in that a well must pass through the saline water in the upper aquifers in order to reach the potable supply in the Jordan. The saline water must be completely excluded from these wells. Some Jordan wells were not constructed well in the past, and many have been abandoned because they produced saline water.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Muscatine
Pottawattamie
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Adair
Madison
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Clarke
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Monroe
Wapello
Jefferson
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Des Moines
Fremont
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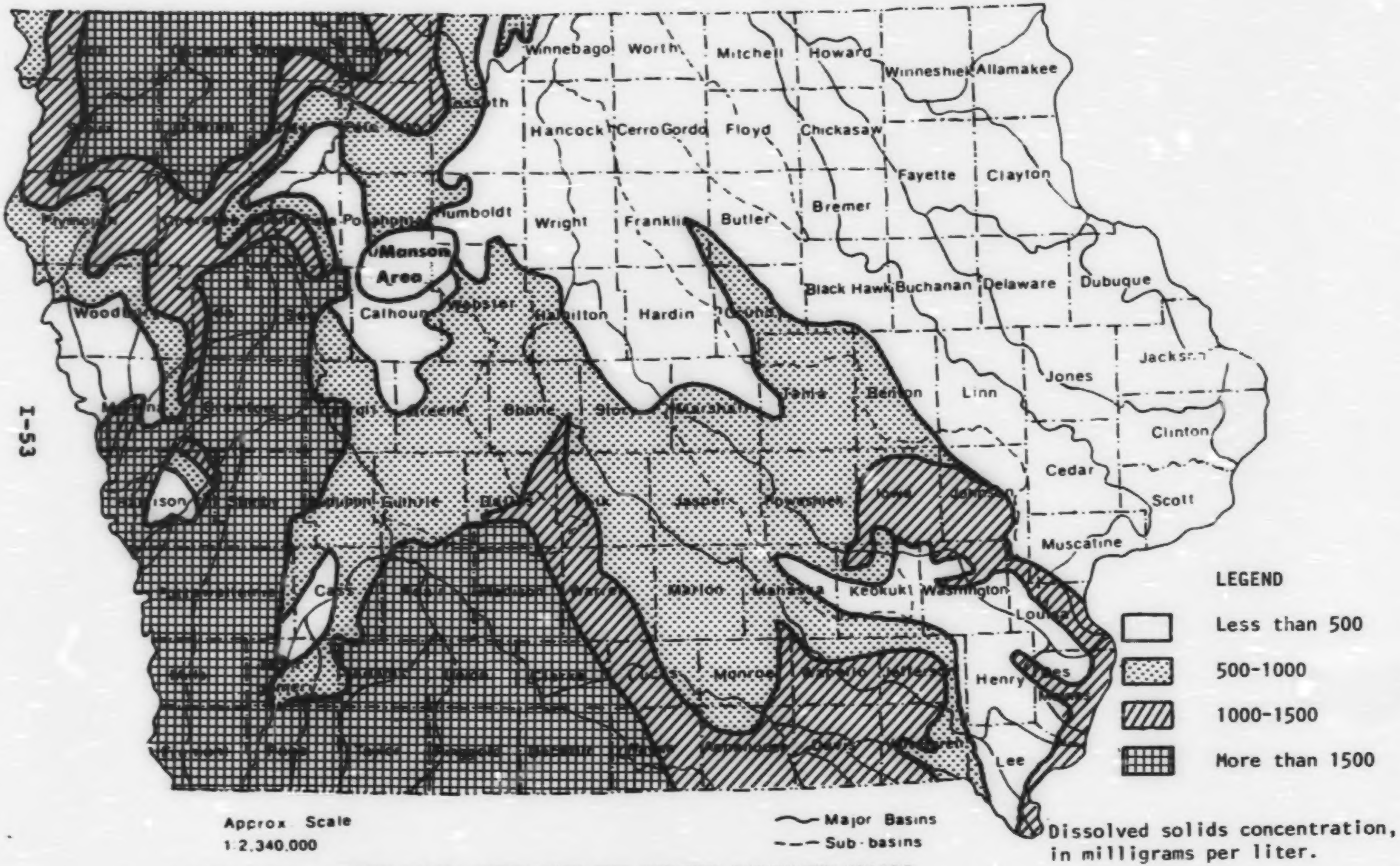
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
500
500
1000
1000
1000
1500
1500
1500
2000
2000
2500
LEGEND
Line of equal dissolved solids concentration, in milligrams per liter
Manson Area
Northern limit of aquifer
Data point
Approx Scale
1 2,340,000
Major Basins
Sub-basins

FIGURE 1-24 DISSOLVED SOLIDS CONCENTRATIONS OF WATER FROM THE JORDAN AQUIFER (4)

Saline water from these aquifers is flowing through these well bores and into other aquifers which contain potable water, thus the potable source is being contaminated. In addition, the saline water, which is very corrosive, can cause the well casing to be eaten away or to disintegrate allowing free passage of the saline water into wells that were once properly constructed.

Summary - Figure I-25 is a summary of Figures I-22, I-23, and I-24 and shows the minimum dissolved-solids content available from bedrock aquifers in the State. The better quality water consistently occurs in north-central, northeastern, and eastern Iowa. The water in all the bedrock aquifers is much more mineralized in the southern, southwestern, and western parts of Iowa.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Clayton
Bremer
Plymouth
Pocahontas
Humboldt
Wright
Franklin
Butler
Manson Area
Black Hawk
Buchanan
Delaware
Dubuque
Woodbury
Calhoun
Webster
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Greene
Boone
Story
Marshall
Clinton
Cedar
Harrison
Guthrie
Jasper
Poweshiek
Iowa
Johnson
Scott
Muscatine
Cass
Marion
Mahaska
Keokuk
Washington
Louisa
Monroe
Henry
Lee
LEGEND
Less than 500
500-1000
1000-1500
More than 1500
Dissolved solids concentration, in milligrams per liter.
Approx. Scale
1:2,340,000
Major Basins
Sub-basins

FIGURE 1-25 AREAS WHERE WATER WITH THE MINIMUM DISSOLVED SOLIDS CONTENT IS AVAILABLE FROM BEDROCK AQUIFERS (4)

REFERENCES

1. Waite, P. J., "Iowa Wind Patterns" The Iowa Geographer, #30, PP28-36, Fall, 1972.

2. Waite, P. J., Climates of the States - Iowa, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C., March, 1967.

3. Waite, P. J., "Freeze Hazards in Iowa" in Weather and Field Crops From Planting To Harvest, Iowa Crop and Livestock Reporting Service, Iowa Department of Agriculture - U.S. Department of Agriculture, 1973.

4. Water Resources of Iowa, Ed. Paul J. Horick, University Printing Service, Iowa City, Iowa, January, 1970.

5. R. H. Shaw and P. J. Waite. The Climate of Iowa III Monthly, Crop Season and Animal Temperature and Precipitation Normals for Iowa, Agricultural and Home Economics Experiment Station, Iowa State University of Science and Technology, Ames, Iowa, April 1964.

6. Ivan L. Burmeister, The Streamflow Data Program in Iowa U.S. Department of Interior, Geological Survey, Water Resources Division, Iowa City, Iowa, 1970.

CHAPTER II - WATER QUALITY

The main objective of water quality management is to protect and enhance the water resources to ensure acceptable conditions for designated uses. Sound management first requires knowledge of the existing water quality resulting from the interaction of man with nature throughout the river basins.

Iowa Water Quality Standards establish a baseline for evaluating adequate stream quality under existing and projected discharge conditions. The National Water Quality Criteria, as proposed by the U.S. Environmental Protection Agency (EPA), provide an additional measure of the adequacy of existing water quality.

Existing water quality for the State has been identified from available data. The data indicate some areas of degraded water quality.

WATER QUALITY STANDARDS

Water quality standards define the constituent levels which will protect the utility of the water resources for multiple uses. Concentrations of water quality parameters in a "pristine" state are difficult to locate or estimate because of the ubiquitous activities of man within the basin. Existing water quality, therefore, is compared to established standards to determine the quality of a stream.

Iowa Department of Environmental Quality Regulations

Regulations promulgated by the Iowa Water Quality Commission specify water quality standards for all surface waters within Iowa. The authority to adapt such standards is found in Sections 32(2) and 35 of Chapter 455B, Code 1973. Specific regulations are published in the 1973 Iowa Departmental Rules, (IDR) and subsequent supplements. These rules appear in the IDR under the heading "Environmental Quality Department".

The most important regulations applicable to the study area are identified in Chapter 16, Section 3, Water Quality Standards of the IDR. This document specifies the water quality requirements for the following use classifications:

Class A - Whole Body Contact Recreation
Class B - Wildlife, Non-body Contact Recreation and Aquatic Life
Class C - Potable Water Supply
General Water Quality Criteria

Class B uses apply to waters which will support both cold and warm water fisheries. Different sets of criteria are enumerated for each use. Tables II-1, II-2, II-3, and II-4 summarize the applicable water quality standards.

TABLE II - 1

WATER QUALITY STANDARDS

Water Quality Parameter	Class A	Class B	Class C
Dissolved Oxygen		At least 5.0 mg/1 during at least 16 hours of any 24-hour period. At all times equal to or greater than 4.0 mg/1.	
pH	Not less than 6.5, not greater than 9.0. Maximum change permitted as a result of a waste discharge shall not exceed 0.5 pH units.	Not less than 6.5, not greater than 9.0. Maximum change permitted as a result of a waste discharge shall not exceed 0.5 pH units.	Not less than 6.5 nor greater than 9.0.
Turbidity	Shall not be increased by more than 25 Jackson turbidity units by any point source discharge.	Shall not be increased by more than 25 Jackson turbidity units by any point source discharge.	
Fecal Coliforms	From April 1 through October 31 the discharge of any effluent which contains human pathogens shall not increase the fecal coliforms in the receiving waters by more than 200 count per 100 ml.	Shall not exceed 2,000 per 100 ml, except when waters are materially affected by surface runoff.	

TABLE II - 1

(continued)

Water Quality Parameter	Class A	Class B	Class C
Temperature		Maximum increase of 5° F. The rate of temperature change shall not exceed 2° F per hour. Maximum allowable stream temperature is 90° F. Maximum increase for lakes and reservoir is 3° F. The rate of temperature change shall not exceed 2° F per hour. Maximum allowable temperature is 90° F.	
Chemical Constituents		The concentrations given in Table II-2 shall not be exceeded at any time the flow equals or exceeds the 7-day, 1-in-10 year low flow unless it is known that the material is from uncontrollable nonpoint sources. All substances toxic or detrimental to aquatic life shall be limited to nontoxic or nondetrimental concentrations in the surface water.	The concentrations given in Table II-2 shall not be exceeded at the point of withdrawal. Allowable levels of radioactive substances are given in Table II-3. All Substances toxic or detrimental to humans or detrimental to treatment processes shall be limited to nontoxic or nondetrimental concentrations in the surface water.

TABLE II-2

WATER QUALITY STANDARDS- CHEMICAL CONSTITUENTS

Chemical Constituent	Class B (1) mg/l	Class C (2) mg/l
Ammonia Nitrogen - N	2.0	---
Nitrate	---	45.0
Phenols (other than natural sources)	0.001	0.001
Total Dissolved Solids	750.	750.
Chloride	---	250.
Arsenic	1.00	0.05
Barium	1.00*	1.00
Cadmium	0.05*	0.01**
Chromium (hexavalent)	0.05*	0.05**
Chromium (trivalent)	1.00*	---
Copper	0.02*	1.00
Cyanide	0.025	0.025
Fluoride	---	1.5
Lead	0.10*	0.05**
Mercury	0.005*	0.005**
Selenium	1.0*	0.01**
Zinc	1.0*	1.00

[1] Not to be exceeded when flow is equal to or greater than the 7-day, 1-in-10 year low flow unless from uncontrollable non-point sources.

[2] Shall not be exceeded at point of withdrawal.

*The sum of the entire heavy metal group shall not exceed 1.5 mg/l.

**Sum of these constituents shall not exceed 1.5 mg/l.

TABLE II - 3

WATER QUALITY STANDARDS- RADIOACTIVE SUBSTANCES - CLASS C

Gross beta activity: Shall not exceed 1,000 picocuries per liter.

Radium 226: Concentrations shall not exceed 3 picocuries per liter.

Strontium 90: Concentration shall not exceed 10 picocuries per liter.

Other radionuclides: Annual average concentration for the 168 hour week as set forth by the International Commission of Radiological Protection and the National Committee on Radiation Protection - Handbook 69.

TABLE II-4

WATER QUALITY STANDARDS-
GENERAL WATER QUALITY CRITERIA

Such waters shall be free from substances attributable to municipal, industrial or other discharges, or agricultural practices that will settle to form objectionable sludge deposits.

Such waters shall be free from floating debris, oil, grease, scum, and other floating materials attributable to municipal, industrial or other discharges, or agricultural practices in amounts sufficient to be unsightly or deleterious.

Such waters shall be free from materials attributable to municipal, industrial or other discharges, or agricultural practices producing color, odor, or other conditions in such degree as to create a nuisance.

Such waters shall be free from substances attributable to municipal, industrial or other discharges, or agricultural practices in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life.

The turbidity of the receiving water shall not be increased by more than 25 Jackson turbidity units by any point source discharge.

EPA Regulations

In conformance with the Federal Water Pollution Control Act Amendments of 1972 (Section 304(a) (1) and (2), Public Law 92-500), the EPA has published Proposed Criteria for Water Quality (1). The major objectives of the EPA water quality criteria are to provide protection of all waters and improve natural water quality. The means by which this will be accomplished is best described by the following:

> "EPA Water Quality Criteria will be incorporated into revised State water quality standards under the direction of the EPA Regions by means of policy guidelines developed by the EPA Office of Water Planning and Standards. Those guidelines have provisions for waters to be exempted from specific criteria on a case-by-case basis for specified periods when naturally occurring conditions exceed limits of the EPA criteria or other extenuating conditions prevail to warrant such exemption." (1)

These criteria define water quality necessary to sustain recreational uses in and/or on the water, and for the preservation and propagation of desirable aquatic biota. This level of quality will ensure the suitability of waters for most other uses as well. Based upon the latest scientific information, these criteria define the water quality necessary to satisfy 1983 interim goals (Section 101(a) (2), Public Law 92-500).

The Proposed Criteria for Water Quality (1) are not used in evaluating water quality for this study. However, a comparison between proposed EPA criteria and DEQ Water Quality Standards for Class B streams (warm water fisheries) is presented in Table II-5 for reference.

Water Quality Criteria Summary

Examination of Table II-5 indicates some differences, but many similarities, between proposed EPA criteria and Iowa Water Quality Standards. Certain parameters not limited by Iowa criteria are to be regulated by the EPA. Criteria comparable to those of the EPA will eventually be incorporated into Iowa criteria. Because these changes have not yet been formulated, Iowa's present standards will be used for purposes of this study.

Iowa standards are either more stringent or comparable to proposed EPA criteria for all parameters except trivalent chromium, lead, mercury, and dissolved oxygen (DO). Differences may exist between the two agencies for other toxic materials; however, since the EPA values are based upon bio-assay determinations of toxic concentrations, a direct comparison is not possible.

Initial review of ammonia levels suggests the EPA critera are much more stringent than Iowa standards. However, the EPA criteria refer to the concentration of un-ionized ammonia while Iowa standards specify total ammonia concentration. The differences between the Iowa 2.0 mg/l total ammonia standard

TABLE II-5

COMPARISON OF WATER QUALITY CRITERIA

Water Quality Parameter	IDEQ Class B Water Quality Standards	EPA Proposed Criteria for Water Quality	Water Quality Parameter	IDEQ Class B Water Quality Standards	EPA Proposed Criteria for Water Quality
ph	6.5 - 9.0	6.0 - 9.0	Fecal Coliforms	200 per 100 ml - Class A waters 2,000 per 100 ml - Class B waters.	2,000 per 100 ml average non-recreational waters 200 per 100 ml average - recreational waters.
Alkalinity	--	30 - 130 mg/1	Dissolved Solids	750 mg/1	Bio-assay to be used to determine limits of tolerance of aquatic ecosystem.
Acidity	--	Addition of acids unacceptable	Temperature	4	5
Ammonia	2.0 mg/1-N (ammonia + ammonium ion)	0.02 mg/1-N maximum (ammonia only) or 0.05[1] of the 96-hour LC_{50}	Pesticides	--	0.01 of the 96-hour LC_{50} for those pesticides not listed in Reference
Cadmium	0.05 mg/1	0.03 mg/1 - hard water[2] 0.004 mg/1 - soft Water	Turbidity	Less than 25 Jackson Turbidity Unit increase from any point source.	Compensation point may not be changed by more than 10 percent
Chlorine (free)	--	0.003 mg/1 - chronic exposure 0.05 mg/1 - 30 minute exposure	Radioactivity	--	8
Chromium (hexavalent)	0.05 mg/1	0.03 mg/1	Dissolved Oxygen	5.0 mg/1 for at least 16 hours of any 24-hour period. Never less than 4.0 at any time.	6.8 mg/1 at 1.5° C 6.8 mg/1 at 7.7° C 6.5 mg/1 at 16.0° C 6.2 mg/1 at 21.0° C 5.8 mg/1 at 27.5° C 5.8 mg/1 at 36.0° C Never less than 4.0 mg/1 for a 24-hour or less period when water tempatures exceed 31.0° C
Chromium (trivalent)	1.0 mg/1	0.03 mg/1			
Cooper	0.02 mg/1	0.10[1] of the 96-hour			
Cyanide	0.025 mg/1	0.05[1] of the 96-hour LC_{50}	Sulfides	--	0.002 mg/1
			Detergents (as LAS)	--	0.2 mg/1 - maximum[1] or 0.05 of the 96-hour LC_{50}

Table II-5 (continued)

COMPARISON OF WATER QUALITY CRITERIA

Water Quality Parameter	IDEQ Class B Water Quality Standards	EPA Proposed Criteria for Water Quality	Water Quality Parameter	IDEQ Class B Water Quality Standards	EPA Proposed Criteria for Water Quality
Lead	0.10 mg/l	0.03 mg/l	Oils	--	No visible oil 0.05 of the 96-hour LC_{50}[1]
Mercury	5.0 ug/l	0.2 ug/l - single occurrance	Phthalate Esters	--	0.3 ug/l
		0.5 ug/l - average concentration	Polychlorinated Biphenyls	--	0.002 ug/l
Nickel	--	0.02[1] of the 96-hour LC_{50}	Tainting Substances	--	6
Phosphorus	--	25 ug/l-P[3] lakes and reservoirs 100 ug/l-P - streams			
Zinc	1.0 mg/l	0.003 of the 96-hour LC_{50}[1]			

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[1] LC_{50} identifies the concentration at which 50 percent of the test organisms die within the stated time period.

[2] Hard water is defined as having a total hardness of 100 mg/l as $CaCO_3$ or more.

[3] Concentrations required to prevent nuisance aquatic plant growths where phosphorus is the limiting constituent.

[4] Refer to Table III-1.

[5] Refer to "Proposed Criteria for Water Quality," EPA, P. 144-170.

[6] Refer to "Proposed Criteria for Water Quality," EPA, P. 141-143.

[7] Refer to "Proposed Criteria for Water Quality," EPA, P. 125.

[8] "Water Quality and Treatment," American Waterworks Association, Inc. 1971, P. 27-32.

and the EPA criteria depend on stream pH as evidenced below:

pH	(NH_4+) (mg/l-N)	(NH_3) (mg/l-N)	Total Ammonia (mg/l-N)
6	39.98	0.02	40.00
7	3.62	0.02	3.64
8	0.36	0.02	0.38

Note: Values based upon the dissociation constant at 25° C.

EXISTING WATER QUALITY

An attempt was made to establish historical water quality trends for the State by researching data from 1960 to the present. However, in general only water quality data collected since 1970 give sufficient detail to indicate stream quality.

The data examined show a varied picture for the rivers studied. Inadequate historical data made trend analysis impossible on many rivers. Based on available data dissolved oxygen, biochemical oxygen demand, ammonia nitrogen and organic nitrogen showed improvement in over half of the streams with data available for analysis. Those parameters with historical data which showed no improvement were nitrate, turbidity and chlorides. The improved picture regarding oxygen depletion and ammonia nitrogen seems to indicate that increased control of point sources is improving stream quality. The lack of improvement in turbidity and nitrate indicates the continued need for more effort concerning nonpoint source pollution.

The concentrations of most water quality parameters are strongly affected by seasonal and hydrologic variations. Temperature changes affect chemical and biological reaction rates. Stream flow variations affect dilution rates, erosion and bottom scour, and correlation with surface runoff.

Total fixed solids concentrations were highest during the spring and late winter. Over 50% of the rivers studied had highest solids concentrations in the spring, and only two rivers had maximum solids levels in the summer or autumn. Turbidity concentrations were generally highest during the spring. Both of these findings are reasonable considering the hydrologic characteristics of Iowa streams. Since highest flows in Iowa normally occur in the spring this relationship could be expected.

Dissolved oxygen lows primarily occurred during winter and early spring. Over 50% of the streams studied had lowest average dissolved oxygen in either winter or spring. This indicates the critical impact of reaeration on the stream. Winter conditions in Iowa produce ice-cover, limiting the ability of the stream to resupply the water with oxygen from the atmosphere.

Ammonia nitrogen concentrations were also highest during the winter. In only one stream were ammonia values highest during another season and in that case it was spring. Again, the lack of reaeration under ice cover creates conditions which allow only slow conversion of ammonia to nitrate.

Insufficient data were available for seasonal analysis of coliform data or hydrologic correlations. Indications are that high coliform levels are associated with runoff and high stream flows. No statistical studies have been conducted to verify this.

Five metals were found to exceed aquatic life classifications of the Iowa Water Quality Standards. These metals were zinc, lead, copper, chromium, and barium. Lead and copper were the only frequent violations with concentrations above the Iowa standards in over 40% of the rivers surveyed. Zinc and barium exceeded standards in two basins and chromium only in the Cedar River.

REFERENCES

1. *Proposed Criteria for Water Quality*, Vol. 1, U.S. EPA, Washington, D.C., October, 1973.

CHAPTER III - NONPOINT POLLUTION SOURCES

Flow contributions into surface waters from sources other than readily identifiable domestic, industrial, commercial, and institutional point discharges may have a substantial impact on water quality. The water resource may be adversely affected by nonpoint discharges associated with combined sewer overflows, urban and rural runoff, and agricultural waste.

Data identifying these pollution vectors are minimal. Remedial measures and construction programs to deal with these problems also frequently lack the clear definition possible for point source pollution abatement programs.

The nonpoint pollution sources have been divided into the following three main areas:

1. general rural runoff,
2. animal feeding operations,
3. urban sources.

Animal feeding operations are sometimes classified as point sources of pollution. Since a large majority of the livestock in the study area is located in small feeding operations and operated as a part of a total farming operation, an analysis of feeding operations has been included in this section.

GENERAL RURAL RUNOFF

Water pollution contributions from agricultural sources are distinctly different from municipal and industrial discharges. While municipal and industrial wastes are discharged as "point" sources, agricultural pollutants often reach the stream as "nonpoint" or dispersed flows. The time and magnitude variance of agricultural discharges is generally related to climatological and meteorological parameters.

Quantitative analysis of the agricultural pollution load is more difficult than for municipal or industrial discharges. Although the mode of transportation for the pollution loads is identical (water serving as the carrier), municipal-industrial loads, are discharged on a relatively continuous basis, carried through collection systems, and treated and discharged to the stream at one location. In the case of agricultural waste loads, potential pollutants originating at or just beneath the surface are transported and discharged to the stream during rainfall runoff or groundwater recharge.

Land Use Practices

Pollution potential from rural areas is heavily dependent upon land use. Land use classifications included in an inventory of the study area are:

1. cropland
2. pasture
3. forest
4. urban
5. other land.

Cropland includes acreage currently tilled, temporarily idle cropland, acreage in soil improvement cover crops not harvested or pastured, cropland being prepared for crops, and all hay land used permanently for forage. Pasture includes grassland or other land used primarily for grazing. Lands which have at least 10 percent tree cover and are capable of producing timber or other forest products are included in the forest category. Other land includes farmsteads, farm roads, animal feeding operations, ditch banks, fence and hedge rows, rural non-farm residences, investment tracts, marshes not used for grazing, borrow and gravel pits, and other uses not classified as cropland, pasture, forest, or urban area.

Parameters

Eight forms of pollution are of particular concern due to their agricultural origin or influence. These include: sediment, animal wastes, residue from industrial processing of raw agricultural products, plant nutrients, forest and crop residues, inorganic salts and minerals, pesticides, and air contaminant fallout.

Those items which most relate to water pollution from general rural land runoff are sediment, plant nutrients, forest and crop residues, inorganic salts and minerals, and pesticides.

Due to the lack of information and apparent rare occurrence of problems from forest and crop residues and inorganic salts and minerals, these items are not included in the development of the potential pollution load on the streams. Pollution attributable to the animal population in the area will be subsequently discussed under the heading Animal Feeding Operations. Although organic-based agri-chemicals do present extreme pollution hazards, insufficient data are available to quantitatively assess the impact upon water quality. Therefore, the following discussion relates only to pollution resulting from sediment, plant nutrients, and organic loads associated with agricultural land practices.

Sediment - Sediment losses are of prime importance. The U.S. Soil Conservation Service and Iowa's one hundred soil conservation districts place particular emphasis on abating this problem. In addition to the aesthetic problems associated with sediment loads, economic disadvantages are incurred by landowners due to decreased productivity, because of soil erosion, and increased maintenance of channels.

Nutrients - Nitrogen and phosphorus are the two plant nutrients of greatest significance in nonpoint runoff. Since animal wastes, plant residues, and fertilizers contain these elements, land under agricultural development is a major nutrient source.

The primary concern regarding discharges of nitrogen and phosphorus is the impact on algal growths. Since these growths are more prolific in quiescent areas, reservoirs and ponds are extremely susceptible to excessive algae populations. Four primary reasons why algal populations have a detrimental effect on water quality include:

1. Algal growths increase the carbonaceous BOD in streams, due to decomposition of dying cells.
2. During daylight hours, algal photosynthetic activity can create high dissolved oxygen levels in the stream which are generally not harmful. During nighttime hours, however, algal respiration may significantly lower the dissolved oxygen level.
3. Turbidity and suspended solids levels in streams may be substantially increased due to growth of algal cells.
4. Algae may impart tastes and odor to the body of water in which they reside as a result of natural metabolic processes, or cell decay.

Excessive plant nutrients and resulting algal growths influence both aesthetics and economics in particular areas. Aesthetic consequences relate to increased turbidity and suspended solids levels, the undesirable appearance of algae populations, and the odor frequently emanating from the decomposition of cell material. Economic disadvantages are associated with the taste and odor imparted to water by algae. Odors are difficult and often impractical to remove from water serving as a potable source of supply. Also, economic loss can be suffered by operators of water-based recreational facilities as a result of excessive algal blooms. As a result, nutrient runoff attributable to agricultural practices is important.

Organics - Although all aspects of water pollution are closely related, the one most frequently referenced is associated with organic materials discharged to the streams. Specifically, pollutants are often classified by their biochemical or chemical oxygen demand (BOD or COD).

During the low stream flow periods, the agricultural contributions of organic material are relatively minor with respect to the contributions from municipal and industrial sources. The oxygen demand of organic materials resulting from nonpoint runoff is imposed upon the stream during short high flow intervals of time similar to the periods of high sediment and nutrient loading.

Eutrophication

Eutrophication is the process of nutrient enrichment of waters and is associated with the deterioration of lakes. Eutrophication causes a number of related changes including increased production of algae and other aquatic plants, and the deterioration of desirable fisheries and water quality. Eutrophication is a natural process which usually takes place over several hundreds to thousands of years as the lake acquires nutrients from the earth, the air, and the remains of plants and animals. Cultural activity can accelerate this process through increased levels of nutrient input.

It is generally believed that lakes originally are oliogotrophic (low in nutrients) with low productivity and ample oxygen. As eutrophication continues, the lake is enriched and productivity and sedimentation increase. The lake basin begins to fill. Ultimately, the eutrophication process leads to extinction of the lake.

Causes Of Eutrophication. In Iowa, one of the major causes of eutrophication is runoff from agricultural lands. Extensive use of artificial fertilizers containing large amounts of nitrates and phosphates has contributed to the high concentrations of these substances in many Iowa surface waters.

It is very difficult to predict the amount of nutrients which can enter a lake without causing nuisance conditions. The nutritional status of certain species of algae can very from lake to lake, or even from different areas of depths of the same lake, as well as over time. Subsurface samples of some algae have been shown to have surplus nitrogen or phosphorus at times when the same species in surface waters were nitrogen or phosphorus limited. No simple relationship can be expected among nutrient loading, nutrient concentration, and production, because of the variety of other influential factors such as depth, extent of shoreline, flow-through and detention times.

Significance of Nutrients - Nutrients such as phosphorus nitrogen, carbon, iron, molybdenum, silica, and many others are required for fresh water algae production. Phosphorus or nitrogen are usually limiting elements which control the level of algae production. Also, the levels of nitrogen or phosphorus entering a lake are more easily controlled by man than other required elements.

In recent years, some researchers have emphasized the role of carbon in algal production. Most studies indicate, however, that algal production is directly proportional to the amount of phosphorus added, and in some cases to the amount of nitrogen, but usually has no obvious correlation with the carbon concentration. Algae can efficiently utilize carbon dioxide at concentrations much lower than that present in the water from atmospheric equilibrium. Thus, in most cases it would be virtually impossible to control the carbon dioxide concentration. Though carbon is not likely to be limiting, there is evidence that factors such as the ratios of various essential nutrients, including carbon, and physical conditions, can regulate the type of predominant algae, even though the total algal biomass may remain the same.

Nutrient concentration has been identified as a significant factor in fostering eutrophication. Where sewage pollution is substantial, sewage, with its nitrogen/phosphorus weight ratio of about two to three, adds phosphorus at a much greater rate than nitrogen. As a result, the added phosphorus reaches levels which are no longer limiting and triggers a productive response. This activity proceeds until either exhaustion of nitrogen, or some other nutrient, or other environmental shift impedes continued production.

Algal production is temperature dependent, with most algal blooms and nuisance conditions occurring during warm summer periods.

Sources of Nutrients - The more common ways in which nitrogen and phosphorus enter waterways include: runoff from undisturbed land, urban land, and agricultural land; industrial discharges and flow from wastewater treatment plants; discharges from boats; precipitation; and biological sources, such as excreted droppings from waterfowl, other birds, animals, leaf fall, and nitrogen fixation. Natural nutrient sources such as runoff from undisturbed land, precipitation, and biological sources generally do not lend themselves to easy control. Sources of nutrients originating from the activities of man can be controlled to some extent.

Effects on Reservoirs - When reservoir sites are flooded, land plants die and organic residues begin to decompose below the rising waters. Nutrients are released and algae and other microrganisms flourish in the nutrient enriched environment. Ten to fifteen years are normally required before biodegradable substances are decomposed and the reservoir becomes stabilized.

Although much research has been conducted dealing with the limnology of impoundments, a great deal of uncertainty still exists in predicting the influence of reservoirs and reservoir operation on water quality. The interrelationships between the various chemical and biological factors within a large body of water are complex. Climatic changes, variations in the terrestrial environment, and other special conditions unique to each individual impoundment make it difficult to determine the exact conditions that will occur in a given reservoir. Normally reservoirs with extensive shallow areas tend to support algae populations and are prone to develop taste and odor problems. Where reservoirs are used to store flood waters, the level is normally lowered during the summer, thus destroying stratification during the most critical period of the year when rates of decomposition are high and algae blooms are common. This is very helpful in preventing the development of extensive algal blooms in the shallow areas.

Preventive Measures - Methods available to control eutrophication include limiting the fertility of the water and providing harvestable crops which can be removed with a concomitant removal of nutrients. The soundest preventive measure is to curb the nutrient input.

Method of Analysis

Evaluation, interpretation, and expression of the data pertaining to agricultural runoff is quite different from the methods normally used for analysis of continuous point source discharges. Due to the nature of these discharges, quantitative values which identify the parameter are difficult to obtain and evaluate. Since contaminants from agricultural land use practices are associated with precipitation and the manner in which it reaches the stream, the variable nature of rainfall, soil moisture content, terrain, land use, and seasonal growth variations, amplify the problems of determining agricultural runoff loads.

In order to evaluate the pollution potential of agricultural practices utilized:

1. available information regarding agricultural runoff to streams should be reviewed,
2. available information on pollution potential should be adjusted to conform with conditions in the basin,

3. potential sediment erosion and nutrient loss values should be applied to the land use classification data, and
4. quantitative pollution loads to the streams in each watershed due to agricultural land use practices should be estimated.

Information on runoff attributable to agricultural land use practices has been developed by various individuals working throughout the midwest United States. Most information has been for experimental plots (less than 5 acres) or small drainage areas (less than 100 acres). The data are applicable to the land use practices in specific study regions, but the quantitative values may be susceptible to considerable variation in a large river basin. The variations of a study region with respect to other areas that have been researched may also have a marked effect upon interpretation of agricultural runoff contributions. Applicable loads, have to be developed through adjustment of loads from other locations to the situation which currently exists in the region.

Various methods have been used to report agricultural runoff contributions. The most realistic approach is to define losses in terms of pounds of material lost per acre per year.

Data on BOD_5 and COD potentials from cropland are limited due to the variability of the discharge and the inert nature of material normally contained in runoff. Contributions obtained from experimental test plots in Ohio (8), using prevailing land management practices, indicates BOD_5 potential of 120 pounds per acre per year and COD potential of 480 to 1,300 pounds per acre per year. Although these are the results of only one investigation, the duration of this study (12 years) and the procedures employed lend a high degree of reliability to the data. The study included crop rotation practices, grasses in rotation, and fertilizer applications.

Pollution Abatement Practices

Two runoff control measures are:

1. improved and more frequent use of soil conservation practices, and
2. increased efficiency of fertilizer applications.

Use of these remedial actions has not been widespread. Only 4 percent of potentially feasible erosion control projects have been constructed in the United States (4). In Iowa, approximately 20 percent of the land susceptible to erosion has been treated.

Although programs for decreasing water pollution are the main concern of this report, there are many additional benefits attributable to better land treatment. Good land management practices decrease the pollution load primarily through retardation of surface runoff from rainfall and snow melt. In doing this, constituents which could cause pollution in the stream are retained on the agricultural land. Since these materials do not reach the stream, economic advantages are accrued to the landowner through decreased soil loss and increased crop productivity through retention of applied fertilizers.

Soil Conservation - Sheet erosion is predominant where the precipitation results from short duration, high intensity storms. Historically, most of the damage in upland drainage areas has been shown to occur during storms with return frequencies of less than 5 years (4). Since these precipitation patterns are characteristic of much of the State, control measures to counter the erosion characteristics should be implemented throughout the State. The three basic principles behind land treatment and construction of control structures for upland control of sheet erosion are:

1. provision for increased soil absorptivity,
2. provision for retardation of surface runoff, and
3. reduction of soil displacement by dissipation of the erosive energy of raindrops at or near the ground surface.

Beneficial land treatment practices for various terrain and soil conditions are identified and recommended in the 1970 Conservation Needs Inventory, (1), for the following categories:

1. Cropland:
    a. Residue and annual cover: Includes use of crop residues, annual cover crops, or other annual

recurring measures on a local basis to increase soil absorptivity and retard surface runoff.

   b. Sod in rotation: Sod in the crop rotation is beneficial to reduce erosion.

   c. Contouring, strip cropping, terracing, and diversions: Contouring is needed to control erosion when land is in cultivated crops. Strip cropping, terraces, and diversions are needed to protect and treat the land on long slopes.

   d. Permanent cover: A change to a permanent cover crop of grass or trees is needed on land unsuited for row or grain crops.

2. Pasture:

   a. Improvement only: Improvement and restoration of pasture conditions through application of recommended management practices and grazing systems provide protection against erosion.

   b. Brush control and improvement: Removal of woody and noxious plants on pastures by chemical or mechanical measures permits establishment of erosion resistant ground cover.

   c. Re-establishment of vegetative cover.

   d. Re-establishment of ground cover with brush control.

3. Forest:

   a. Timber stand improvement: Improves cover conditions where biologically feasible.

Fertilizer Application - Nitrogen and phosphorus contributions to streams have normally been associated with surface runoff from agricultural land. Since ammonia-nitrogen applied to the soil is rapidly oxidized to nitrate, which is very soluble in water, nitrate-nitrogen is transported to the stream through groundwater recharge. In contrast, phosphorus applied to the soil is strongly fixed by various metallic ions associated with the soil particles. Since these compounds are highly insoluble in water, phosphorus is primarily transported to the stream attached to soil particles lost through erosion (6). Studies conducted during periods of high stream flow resulting from surface runoff have indicated that agricultural land is a substantial contributor of both nitrogen and phosphorus to the stream (5).

Without additional investigations into the transport of nutrients to the streams, it can be concluded that contributions in agricultural areas are primarily associated with fertilizer applications. One method of reducing nutrient runoff to streams is through more efficient and effective use of fertilizers. This includes better scheduling and improved mechanical efficiency of applications, elimination of over-fertilization, and use of the fertilizer best suited to the particular crop and soil type.

A major concern in implementing these recommendations is related to possible reduced crop yield. Studies have indicated that increased plant usage of the applied fertilizer can be obtained from proper scheduling of application. For example, application of fertilizer too early in the growing season may lead to excessive losses to the stream through runoff and ground water recharge. Additional studies have shown that corn yields generally do not substantially increase with fertilizer rates in excess of 200 pounds of nitrogen per acre, 75 pounds of phosphorus per acre, and 150 pounds of potassium per acre (7).

ANIMAL FEEDING OPERATIONS

Iowa is one of the largest cattle feeding states in the United States and leads the nation in total livestock production. In 1972, 24 percent of the total swine production in the nation was produced in Iowa. Also in 1972, Iowa was second only to Texas in total cattle numbers. Iowa also has the largest number of individual livestock operations of any state in the nation, with over 100,000 Iowa farms having livestock. Although on many of these farms, the number of livestock is small and livestock are not necessarily fed in a confined situation, this does illustrate that a very large number of livestock operations does exist.

Most Iowa animal feeding operations are not of the size generally associated with commercial feeding enterprises, as most operate as part of a total farming operation. Feeding operation pollution problems in Iowa have been relatively localized, affecting small streams or small portions of streams.

With the current emphasis on all elements of water pollution control, it is hoped that the animal producer will recognize the need and take action to control a relatively monumental waste disposal problem. For example, cattle feedlot waste discharges normally reach a stream only during runoff periods. Nevertheless, the contribution is so large that numerous adverse effects on water quality can result. Fish kills have been reported downstream of large feeding operations following heavy rainfalls. This results from organic material which washed into the stream and subsequently depleted the available oxygen.

Existing Legislation

The first regulations in Iowa to control waste discharges from open cattle feeding operations [Section 1.3(455B) of the rules of the old Water Pollution Control Commission, Iowa Departmental Rules, 1971] were adopted in October, 1969. An expansion of these rules is found in Section 16.3(455B) of the rules of the Water Quality Commission, Iowa Departmental Rules, 1973, covering all types of livestock and poultry operations. The present regulations require that new or expanding animal feeding operations register before they commence construction, but existing operations are not required to register until notified of the need by the DEQ. Animal feeding operations are defined in the regulations by the following:

a. An open feedlot is one or more unroofed or partially roofed adjacent or nearby animal enclosures on a single property where the following animal populations and animal population densities exist:

Species	Animal Population Exceeds	Square feet of lot area per animal is less than
Cattle, Beef	100	600
Cattle, Dairy	70	600
Swine, Butcher & Breeding (over 40 lbs)	500	100
Swine, Feeder Pigs (below 40 lbs)	4,000	15
Sheep	1,200	60
Turkeys	6,000	10
Chickens, Broiler	30,000	2
Chickens, Layer	20,000	2

b. Confinement feeding operation is one or more roofed or partially roofed adjacent or nearby animal enclosures on a single property from which wastes are removed as a liquid or semi-liquid and in which the maximum number of animals confined at one time exceeds:

Species	Animal Number Exceeds
Cattle, Beef	50
Cattle, Dairy	40
Swine, Butcher & Breeding (Over 40 lbs)	250
Swine, Feeder Pigs (Below 40 lbs)	1,800
Sheep	600
Turkeys	3,000
Chickens, Broiler	15,000
Chickens, Layer	9,000

The present animal feeding operations pollution program in Iowa is based upon a dual registration-permit procedure. Under this procedure, registration is required by animal feeding operations which meet specified registration criteria.

a. Registration of those open feedlot operations is required if one or more of the following conditions exist:

(1) The number of animals confined in an open feedlot exceeds:

Species	Animal Number Exceeds
Cattle, Beef	1,000
Cattle, Dairy	700
Swine, Butcher & Breeding (Over 40 lbs)	4,500
Swine, Feeder Pigs (Below 40 lbs)	35,000
Sheep	12,000
Turkeys	55,000
Chickens, Broiler	270,000
Chickens, Layer	180,000

(2) The feedlot contributes to a watercourse draining more than 3,200 acres of land above the lot and the distance from the feedlot to the nearest point on the affected watercourse is less than:

Species	Distance to Watercourse is Less Than (Feet per 100 Animals)
Cattle, Beef	200
Cattle, Dairy	300
Swine, Butcher & Breeding (Over 40 lbs)	50
Swine, Feeder Pigs (Over 40 lbs)	10
Sheep	20
Turkeys	5
Chickens, Broiler	1
Chickens, Layer	1

(3) The runoff water from a feedlot or overflow from a waste collection, storage or treatment facility flows directly into a tile line or other buried conduit, drainage well, pumped well, abandoned well or sinkhole, or discharges directly into a gravel pit, rock quarry or a lake or pond when such lake or pond is located on property not wholly owned by the registrant.

b. Registration of those confinement feeding operations described in 16.3(1) "b" is required if one or more of the following conditions exist:

(1) The number of animals in a confinement feeding operation exceeds:

Species	Animal Population Exceeds
Cattle, Beef	100
Cattle, Dairy	70
Swine, Butcher & Breeding (Over 40 lbs)	500
Swine, Feeder Pigs (Below 40 lbs)	4,000
Sheep	1,200
Turkeys	6,000
Chickens, Broiler	30,000
Chickens, Layer	20,000

(2) Overflow or other waste discharge from a waste collection, storage or treatment facility contributes to a watercourse.

(3) Overflow or other waste discharge from a waste collection, storage or treatment facility flows directly into a tile line or other buried conduit, drainage well, pumped well, abandoned well or sinkhole, or discharges directly into a gravel pit, rock quarry or a lake or pond when such lake or pond is located on property not wholly owned by the registrant.

c. Those confined feeding operations not included in requirements of these rules shall be required to register if investigation by the Iowa Water Pollution Control Commission determines that such operations are causing pollution or may reasonably be expected to pollute waters of the State.

Registered animal feeding operations are subsequently investigated to determine whether the operations are causing or have the potential for causing water pollution. If there is evidence of water pollution, or a potential for causing water pollution exists, the feedlot operator is required to construct control facilities in accordance with a plan submitted to and approved by the DEQ, and to obtain an operation permit for the facility.

As of April, 1976, approximately 1,200 operators had registered with the DEQ. Although the number of registered operators is a small percentage of the total livestock operators in Iowa, the registered operations include many of the largest facilities in Iowa.

Pollution Parameters - Feeding Operations

The major objectionable constituents in waste discharges from animal production facilities are suspended solids, nutrients, and organic material. Suspended solids discharging to streams result in the formation of sludge banks in the watercourse. Since these deposits consist largely of organic material (in contrast to the inorganic contribution from rural runoff), they become aesthetically unacceptable from sight and odor considerations. Additional oxygen requirements can be of sufficient magnitude to create a severe ecological imbalance in particular reaches of the streams. Beneficial organisms may be eliminated from the stream and increased populations of unfavorable growths may result.

Similarity exists between nutrients contained in rural land runoff and feeding operation runoff. Primary constituents again are the elements of nitrogen and phosphorus. The same detrimental effects associated with nutrient runoff from agricultural land are also caused by discharges from feeding operations.

In the previous analysis of general rural runoff, organic loads were fairly minor relative to the other pollutional discharges. However, in the case of feeding operation runoff, BOD and COD can comprise extremely high percentages of the total pollutant load. Large concentrations of organics contained in feeding operation runoff may have devastating effects upon the receiving streams.

Pollution Potential - Feeding Operations

Data presented in Table III-1 are representative values for objectionable constituents from animals subjected to confined feeding.

TABLE III-1

CHARACTERISTICS OF ANIMAL WASTES (3)

		Constituents lb/day/animal				
Animal	Weight	Total Solids	Nitrogen	Phosphorus*	COD	BOD_5
Cattle	1,000 lbs	3.62 to 9.0	0.26	---	3.26	1.02
Swine	100 lbs	0.5 to 0.97	0.032 to 0.07	0.025	0.47 to 0.96	0.20 to 0.56
Poultry	4-5 lbs	0.057 to 0.084	0.003 to 0.0036	0.0026	0.033 to 0.057	0.006 to 0.032

* Phosphorus as P_2O_5

The quantity of pollution load actually reaching the stream from a livestock operation is quite variable. Type of lot surface, precipitation, distance to stream, enclosed or semi-enclosed facilities, and concentration of animals all influence the characteristics of waste discharges.

Pollution Abatement Practices - Feeding Operations

Pollution potentials attributable to animal production operations are large, but manageable with proper design and maintenance of control facilities. Basic principles associated with municipal and industrial wastewater treatment are also applicable for handling animal wastes. These include:

1. Decrease the pollution contribution, as far as economically feasible, at the source.

2. Reduce the remaining pollution load to an acceptable level with the most applicable and cost-effective treatment scheme.
3. Apply the residue from the treatment process to land in a manner that has minimal adverse environmental impact.

The above abatement practices closely parallel the regulations for effluent guidelines prepared by the EPA (40 Code of Federal Regulations, Part 412 - FEEDLOTS CATEGORY). In all instances, direct discharges are eliminated and utilization of recyclable materials is practiced.

Controlling pollution at the source requires implementation of means for dealing with precipitation and resulting runoff. Adverse effects of precipitation are eliminated by instituting totally confined livestock operations and can be minimized in open production areas through diversion of upstream runoff. Numerous treatment alternatives have been proposed and used for animal production facilities. The basic premise of each approach is to minimize or eliminate the quantity of material reaching a stream.

Certain treatment concepts are applicable to each animal operation, however, specific requirements of a production facility necessitate distinct differences in portions of treatment schemes. The following discussion relates to recommended treatment practices for the categories of cattle, swine, and poultry operations.

Cattle Feeding Operations - Optimum animal production levels and economic feasibility influence the amount of pollution reduction possible at the source. Treatment is required to handle the remaining pollution load. The following management considerations influence the pollution potential (2):

1. Increasing cattle density beyond a critical point decreases the runoff contribution per animal.
2. General housekeeping practices around feeding operations may have a variable impact upon pollution contributions depending upon the season, lot surface and frequency of lot cleaning.
3. Potential runoff pollution increases as wastes accumulate on the lot surface until a maximum level is reached. Beyond this value, the pollution potential remains constant until the lot is cleaned.

Four elements are required to adequately handle the waste materials. They are:

1. debris basins to retain solid material,
2. retention basins to collect remaining solids, and the liquid waste portion,
3. ultimate disposal of material upon agricultural land, and
4. diversion of upstream runoff around the lot.

The debris basin is constructed downstream of the feeding operations to allow deposition of solids contained in the runoff. Design considerations include:

1. ease of maintenance and operation, and
2. storage capacity based upon the number of animals and the average annual runoff.

Solids collected in this facility should be removed at least annually. Proper land application of these separated solids is then recommended.

The retention facility is normally designed with capacity for handling runoff from a storm with a recurrence frequency of approximately once in 10 years. Other parameters follow those presently used for conventional aerobic waste stabilization lagoons. A major distinction is that no direct discharge from this facility is allowed under normal weather conditions. Therefore, no degradation in water quality will be realized.

The last, and most important, element of the treatment scheme is the land application of retention basin contents. With increased awareness by management, proper location of feeding operations will include evaluation of the availability of land for irrigation. In addition to providing ultimate disposal of lot runoff material, some fertilizer value is obtained from this liquid.

Properly designed and operated, the above treatment scheme requires minimum operational attention. Water pollution from lot runoff is almost completely eliminated since no precipitation falling on the lot reaches the stream directly.

Swine Operations - Although the general concepts of swine operations are similar to cattle feeding operations, specific differences in animal management necessitate treatment variations. Since many swine are produced in a semi-enclosed or totally enclosed facility, precipitation may no longer be a concern.

Basic elements included in a treatment scheme are a retention structure and land disposal facilities. A retention structure can be located directly beneath or removed from the production building.

For either location, the concept is identical. Material is collected and transported hydraulically to the retention structure. The facility is sized to handle the capacity of the production operation. Waste material is removed at regular intervals and applied to agricultural land.

Poultry Operations - In contrast to cattle and swine operations, most poultry wastes are handled in a dry form. The size of the animal, manure quantities, and manure characteristics allow retention of the material within the production facility.

Manure retained beneath the fowl can be allowed to decompose (compost) in place or can be removed at frequent intervals for disposal. Sizing of the facilities necessitates defining the disposal mode to be used. In either case, the material may be removed from the production facility and applied directly to agricultural land.

URBAN RUNOFF

In urbanized areas, surface runoff and combined sewer overflows can adversely affect the utility of the water resource. Some contaminants in urban runoff discharged to a watercourse are animal droppings, eroded soil, tire and vehicular exhaust residues, deicing compounds, pesticides, fertilizers, air pollution fallout, and decayed vegetation. Relatively poor flow characteristics of combined sewers during dry weather (i.e., carrying sanitary waste flow only) cause deposition and accumulation of the solids in the sewerage system. These solids can be flushed from the system during precipitation or snow melt and are discharged into the stream.

The impact of urban runoff upon the aquatic environment is difficult to quantify based upon present information. In addition to having almost no data available technical literature has not resolved the impact of these sources upon streams.

Corrective measures for urban storm-water runoff pollution abatement may be classified as preventive or curative. Preventive practices may consist of proper conservation techniques on land development projects to reduce sediment loss. Also, improved collection of material through normal municipal cleaning operations should reduce objectionable materials from reaching the streams.

Combined Sewer Overflows

Impact of combined sewer overflows on the aquatic environment is difficult to quantify, based upon available information. Hydrologic, climatologic, and topographic differences between research project areas make extrapolation of reported literature difficult. Delineation of data applicable to the region was necessary to identify the relative magnitude of the problem. Following are estimates of typical combined sewer overflow discharge characteristics.

Constituents	Concentration (mg/l)
BOD_5	120
COD	380
Suspended Solids	450
Phosphorus (P)	4
Ammonia Nitrogen (N)	6

The actual concentration of the various constituents can be expected to vary considerably. Concentrations will vary in the same drainage area due to differences in topography and land use. High suspended solids concentrations will normally be reported following an extended period of dry weather. Considerable variation in the waste concentration is also encountered at an outfall throughout the duration of a storm. Higher constituent concentrations are normally reported during the initial stages, or "first flush", with lower concentrations occurring as the storm progresses.

There are many workable solutions to the combined sewer overflow problem based upon combinations and variations of the following alternatives. A detailed study is required to arrive at the optimum solution to the total problem in any given community. The three major alternative solutions are:

1. Complete separation of the storm and sanitary sewer systems.
2. Treatment at, or near, individual points of overflow.
3. Collection of combined overflow with treatment at a single site.

Complete Separation - There are many problems associated with complete separation of an existing combined sewer system. In addition to disturbing normal traffic flow and other surface activities, numerous conflicts arise with existing pipes and other utilities located under street surfaces. If a separate system is installed, it is also necessary to make extensive house connection changes within the system.

Having accomplished separation, it must also be emphasized that urban storm-water runoff can still be a significant source of stream pollution.

Detailed engineering studies are required to identify viable pollution abatement alternatives and associated costs. A comprehensive combined sewer inventory was conducted by the Federal Water Pollution Control Administration (now the EPA) in 1967. Results of this survey indicated that costs for complete separation ranged from $100 to $29,000 per acre in the Midwest with an average of $5,720.

Specific tangible elements are included in this value while other less obvious items are not. Necessary costs for plumbing alterations, street repairs, and utility relocations are included. Business disruptions, traffic detours, utility service interruptions, and miscellaneous associated elements were not identified.

Individual Treatment - This solution would provide treatment facilities for all major combined sewer overflow points in a given community. It is impracticable in most areas due to lack of space for construction of necessary facilities. Treatment facilities must be sized to handle the peak flow rate or provide large storage basins to hold excess water until it can be treated. Other disadvantages inherent with this system are:

1. multiplicity of facilities,
2. normally low treatment efficiency,

3. sludge handling and disposal problems,
4. operational problems associated with maintaining staff to operate the facilities for short durations during and following storms, and
5. adverse impact upon local environment due to numerous plant locations.

Treatment at One Location - The third solution consists of collecting water from existing combined sewer overflows for conveyance to a single treatment facility. The principal advantage of this system over the multiple plant alternative is that a higher degree of treatment can be achieved at a lower cost. Other advantages are:

1. The treatment facility can be located to permit construction of storage lagoons at the site.
2. Operational problems associated with the facility staffing are minimized.
3. Sludge handling and disposal is simplified.
4. Adverse impact upon the local environment is minimized.
5. There is minimal disturbance of existing developed areas.

The main disadvantages associated with this system are:

1. Extensive collection sewers are required to convey water to a single treatment location.
2. A reduction of flow may occur in some urban

streams, as a result of collection of water in the conveyance system.

3. A large land area is required for the treatment facility.
4. Large interceptors will be required to collect and convey the overflow quantities to storage and treatment facilities.

Treatment facilities would typically be located near the affected streams or rivers downstream from the community.

Biological treatment of storm water has been evaluated in detail by various researchers. It is generally concluded that biological systems cannot be operated in a manner that responds satisfactorily to the intermittent nature of storm flows, however, effective physical-chemical treatment methods can be used to produce satisfactory effluent quality. The treatment scheme evaluated for this study consists of holding lagoons, clarification with polymer addition, multimedia filtration, and effluent chlorination. For evaluation purposes, the effluent from the holding lagoons was assumed to be of a primary treated quality. The effluent quality after each treatment unit process has been estimated and is presented in Table III-2. The following considerations relate to components of the treatment system:

1. Clarification with polymer addition is recommended for suspended solids, BOD_5, and COD removal.

2. Multi-media filtration is provided to remove about 90 percent of the suspended solids carryover from clarification.

3. Chlorination will be provided for disinfection purposes. This will reduce the coliform count to a level of 200 per 100 ml.

TABLE III-2

COMBINED SEWER OVERFLOW EFFLUENT QUALITY

	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)	Phosphorus (mg/l - P)	Nitrogen (mg/l - N)
Without Treatment					
Combined Overflow	120	380	450	4	6
With Treatment					
Storage Lagoon	78	250	230	4	6
Primary Clarification	50	160	110	3.6	6
Multi-media Filtration	27	80	11	3.4	6
Chlorination	27	80	11	3.4	6

A detailed study would be required to size conveyance systems, storage facilities, and treatment units and to estimate their respective cost at any given location in the state.

For purposes of this study, a hypothetical case with a combined sewer service area of 400 acres was assumed.

Combined sewer overflow collection and treatment facilities have been designed to handle peak flow rates resulting from a two-year return frequency storm. The volume of water requiring treatment was based upon a two-year return frequency storm with a 12-hour duration, encompassing the entire contributing drainage area.

Although runoff could vary considerably within the state, depending upon land use and antecedent precipitation, a combined sewer overflow volume of approximately 16 million gallons will be assumed as a typical flow that could be expected from a two-year, twelve-hour storm for any general location in the basin. Storage facilities sized to hold 15.2 million gallons and a 2 mgd treatment plant could be used to treat this flow. Total cost of the conveyance system, storage, and treatment facilities is estimated at $2,280,000. Based upon estimated annual flows, annual operation and maintenance costs of $43,000 per year are estimated.

In an average year, approximately 101 million gallons of combined overflow would be collected and treated. Approximately 39 tons of BOD_5 and 185 tons of suspended solids would be removed from this flow, which would otherwise be discharged to the stream. Relating this to the cost of providing and maintaining the facilities, a unit cost of approximately \$6,100 per ton of BOD_5 or \$1,300 per ton of suspended solids removed is indicated.

Although actual conditions encountered at individual locations would require different design criteria than those used, the hypothetical situation provides a means of determining rough approximations of costs associated with the remedial measures.

Storm Water

Storm water runoff consists of storm sewer discharges in communities served by separate sewer systems and can also include combined sewer overflow where communities are served by both combined and separate systems.

Pollution problems associated with storm-water discharges from separate storm sewers are similar to those identified for combined sewer overflows. The primary distinction is the lack of sanitary sewage. The remaining sources contribute identical constituents to the storm sewer system but generally at low concentrations.

Anticipated quality and quantity of the storm water have been determined by methods previously described for combined sewer overflows. The concentrations presented below for each constituent in typical storm sewer discharges represent averages during a precipitation event.

Constituent	Concentration (mg/l)
BOD_5	28
COD	325
Suspended Solids	1,500
Phosphorus (P)	2
Ammonia Nitrogen (N)	1

Comparison of the suspended solids values indicates that in a completely separate sewer system, storm-water runoff would contain more than three times the load discharged with combined sewer overflows. The reason for this increase is that during periods of storm flow, a large percentage of the heavier inorganic solids are retained in the combined sewer system. This results in substantially less material passing through the overflows. In a separated system, this material is discharged directly to the stream via the storm sewer.

A system similar to that developed for correction of combined sewer overflows can be used for storm water runoff. The collection systems would be located adjacent to natural stream channels, with holding lagoons and treatment facilities at some downstream location. The treatment facility could use identical unit processes to achieve a satisfactory effluent. A major distinction between treatment of the two waste streams is the collection system. Much larger conveyance pipes are required to collect all of the discharges. In addition, the treatment plant and storage lagoons have to be increased to accommodate the larger flow.

Table III-3 indicates the effluent quality after various treatment processes, assuming that all flow is due to storm sewer discharges. Where storm water runoff contains both combined sewer overflow and surface runoff, a weighted average of these flows could be used to estimate the water quality.

TABLE III-3

STORM WATER EFFLUENT CONCENTRATIONS

	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)	Phosphorus (mg/l - P)	Ammonia Nitrogen (mg/l - N)
Without Treatment					
Urban Runoff	28	325	1,500	2	1
With Treatment					
Storage Lagoons	16	210	750	2	1
Primary Clarification	11	140	375	1.8	1
Multi-media Filtration	6	70	37	1.7	1
Chlorination	6	70	37	1.7	1

A hypothetical situation similar to the one developed for the combined sewer overflow collection and treatment facilities has been developed for storm water runoff control to determine cost estimates. The assumption has been made that the entire community is served by a separate sewer system. A sewer service area of 1,500 acres has been used since this approximates the size of the average municipality.

A two-year return frequency storm with a 12-hour duration has been used to size collection and treatment facilities.

Use of the above assumptions and information developed earlier for combined sewer overflow indicated approximately 91 million gallons of storm water would be collected from the two-year 12-hour storm. Storage facilities sized to hold 87 million gallons and a nine mgd treatment plant could be used to treat this flow. Total cost of the conveyance system, storage, and treatment facilities is estimated to be approximately $8,390,000. Average operation and maintenance costs are estimated to be about $217,000 per year.

In an average year, approximately 807 million gallons of storm water would be collected and treated. Some 74 tons of BOD_5 and 4,900 tons of suspended solids would be removed from this flow, which would otherwise be discharged to the stream. Relating this to the cost of providing and maintaining the facilities, a unit cost of approximately $12,700 per ton of BOD_5 or $190 per ton of suspended solids removed is indicated.

Actual conditions encountered at individual communities may require different solutions to the urban runoff problem. However, the hypothetical situation used provides a means of determining an approximate cost associated with remedial measures.

CONCLUSIONS

Elements necessary for identification of the existing pollution loads, required solutions, and the resultant pollution abatement practices have been indicated for general rural runoff, feeding operations and urban nonpoint wastes. These data indicated that:

1. Rural runoff pollution may be abated through implementation of good conservation practices. Complete retention of the soil is not feasible. Correct conservation practices should considerably reduce sediment contributions to the stream.
2. Pollution problems associated with feeding operations are localized, affecting small streams and relatively short lengths of affected streams. In most instances, remedial measures should not place an unmanageable burden upon the livestock producer.
3. Detailed engineering evaluations are required to adequately define the correct combination of the remedial measures necessary to alleviate combined sewer overflow and storm water runoff sources for individual communities or locations.
4. A collection system conveying the flow from only combined sewer overflows, or in combination with storm sewer discharges, to a single treatment location provides one possible solution to urban runoff pollution.

REFERENCES

1. Conservation Needs Inventory, Iowa Conservation Needs Committee, 1970.

2. The Economics of Clean Water - Animal Waste Profile, Federal Water Pollution Control Administration, Volume 11, March, 1971.

3. Loehr, R. C., "Pollution Implications of Animal Wastes--A Forward Oriented Review", Environmental Protection Agency Report 13040-07, 1968, Reprinted 1973.

4. Moore, W. R. and Smith, C. E., "Erosion Control in Relation to Watershed Management." Journal Irrigation and Drainage Division, American Society of Civil Engineer, 94, 321, 1968.

5. Morris, R. L. and Johnson, L., "Buffalo Bill Watershed Agricultural Runoff and Waste Load Allocation Study" State Hygienic Laboratory Report No: 75-10. University of Iowa, Iowa City, Iowa, 1974.

6. Smith, G. E., Statement to U. S. Senate Subcommittee on Air and Water Pollution, April, 1971.

7. Webb, J. R., Muscatine Journal, June, 1971.

8. Weidner, R. B., et al., "Rural Runoff as a Factor in Stream Pollution." Journal Water Pollution Control Federation, 41, 377, 1969.

CHAPTER IV - SEGMENT ANALYSIS METHODOLOGY & WASTE LOAD ALLOCATIONS

The ability of a stream to maintain an acceptable dissolved oxygen (DO) concentration is an important consideration in determining its capacity to assimilate wastewater discharges. Microbial oxidation of organic and certain inorganic matter present in wastewater uses dissolved oxygen. Oxygen supplied principally by reaeration from the atmosphere will replace any dissolved oxygen lost through oxidation processes. If, however, the rate of oxygen use, exceeds the rate of reaeration, the DO concentration may decrease below minimum allowable standards.

To predict the variation in DO, as well as ammonia concentration in streams, a computer-based mathematical model was used. Input data for the model was developed from existing information and field investigations of the streams. When necessary, conservative assumptions have been made that tend to assure a high degree of protection for water quality without necessitating unrealistically stringent effluent limitations. Future sampling should help to verify particular constants and assumptions used, and improve the validity of the model. It is felt that with available data, a reasonably accurate prediction of the impact of different wastewater loads or treatment arrangements upon the DO and ammonia concentrations may be performed, and that determination of wastewater discharges that will not result in violation of water quality standards is possible.

THEORY AND METHODOLGY

Dissolved oxygen concentrations in streams are controlled by atmospheric reaeration, biochemical oxygen demands (carbonaceous and nitrogenous), algal photosynthesis and respiration, benthal oxygen demands, temperature, and the physical characteristics of the stream. Many of these factors are difficult, if not impossible, to accurately assess.

Photosynthesis can produce large quantities of oxygen during the day if algae are present in the stream. Conversely, at night algal respiration creates an oxygen demand. Research efforts have attempted to fit harmonic functions to this phenomenon, but with limited success, therefore, no allowance for diurnal fluctuations in oxygen levels is included in the computer model.

Benthal oxygen demands result from anaerobic decomposition of settled organic material at the bottom of the stream. These reactions release carbonaceous and nitrogenous organic materials which create biochemical oxygen demands. The inclusion of benthal oxygen demands in the model requires extensive field surveys to determine the areal extent of sludge deposits within a stream and coefficients that describe the release into the water. Since the impact is minor in most instances and no data are available describing sludge deposition areas, no benthal oxygen demands are included in the model formulation.

Model Equation

A complete mathematical model to describe DO concentrations within the stream would include all significant factors. Natural systems cannot presently be expressed mathematically with absolute certainty, but reasonably accurate predictions can be made through realistic assumptions concerning the reaeration phenomenon and deoxygenation caused by carbonaceous and nitrogenous biochemical oxygen demands (BOD). Specific values obtained in detailed field investigations from other locations, with particular emphasis placed upon data collected in Iowa, provide satisfactory information for defining ranges of coefficient values to be investigated.

Nitrogenous BOD is due to the oxidation of ammonia to nitrates by certain species of bacteria. This oxidation process is called nitrification. Nitrification is a two-step process whereby a specific bacterial species oxidizes ammonia to nitrite and a different bacterial species oxidizes the nitrite to nitrate. Approximately 4.5 mg/l of oxygen are required to oxidize 1.0 mg/l of ammonia (expressed as nitrogen) to nitrate, although this value may vary between 3.8 and 4.5 mg/l. Since secondary wastewater treatment plant effluents quite commonly contain ammonia nitrogen levels of 10 mg/l, the equivalent nitrogenous BOD (should all the ammonia be converted to nitrates) is approximately 45 mg/l. This is greater than the carbonaceous BOD of most secondary effluents.

For the modeling program, a modified version of the Streeter-Phelps equation for DO deficit within the stream was used. This approach recognizes both carbonaceous and nitrogenous BOD and atmospheric reaeration. Effects of photosynthesis and benthal oxygen demands are not considered. The modified Streeter-Phelps Equation is as follows:

$$D(t) = \frac{K_1 L_o}{K_2 - K_1} (e^{-K_1 t} - e^{-K_2 t}) + \frac{K_n N_o}{K_2 - K_n} (e^{-K_n t} - e^{-K_2 t}) + D_o e^{-K_2 t} \quad (1)$$

Where:

$D(t)$ = DO deficit at time t.

D_o = Initial DO deficit.

L_o = Intial ultimate carbonaceous BOD.

N_o = Initial nitrogenous BOD.

K_1 = Carbonaceous deoxygenation rate constant.

K_n = Nitrogenous deoxygenation rate constant.

K_2 = Reaeration rate constant.

In this equation, the rates of oxygen use due to both carbonaceous and nitrogenous BOD are expressed as first order reactions. This is an accepted procedure for the carbonaceous demand, but represents a simplification for the nitrogenous demand.

Ultimate carbonaceous and ammonia BOD concentrations as a function of time (t) are calculated as follows:

$$L(t) = L_o e^{-K_1 t}$$

$$N(t) = N_o e^{-K_n t}$$

Where:

$L(t)$ = Ultimate carbonaceous BOD at time (t).

$N(t)$ = Ultimate nitrogenous BOD at time (t).

Since nitrification is a two-step process, many researchers have proposed that it is a second order reaction, although no practical DO prediction equation has been developed in this form. Since nitrogenous BOD's are too great to ignore, most developed models assume that it is a first order reaction. The present investigation has also used this assumption.

Nitrifying bacteria are generally present in relatively small numbers in untreated wastewaters. The growth rate at 20°C is such that the organisms do not exert an appreciable oxygen demand until about 8 to 10 days have elapsed. This lag period may be reduced or practically eliminated in a stream receiving large amounts of secondary effluent containing seed organisms. In biological treatment systems, substantial nitrification can take place with a resultant build-up of nitrifying organisms. These nitrifying bacteria can immediately begin to oxidize the ammonia present and exert a significant oxygen demand in a stream.

It is known that the biological nitrification process is generally more sensitive to environmental conditions than carbonaceous decomposition. The optimal temperature range for growth and reproduction of nitrifying bacteria is 26° to 30°C. It is generally concluded that the nitrogenous BOD will assume greatest importance in small streams which receive relatively large volumes of secondary wastewater effluents during the low flow, warm weather periods of the year (August and September). These conditions were used for the low flow determination of allowable effluent characteristics during summer periods. During winter low flow periods (January and February) nitrification will probably have limited influence upon the oxygen demand due to the intolerance of nitrifying bacteria to low temperatures. During analysis of winter low flow conditions, no nitrification was assumed to occur.

Rate Constant Determination

The carbonaceous deoxygenation rate constant (K_1) for most streams will vary from 0.1 to 0.5 per day. Early work by Streeter and Phelps (1) determined an average value for the Ohio River of 0.23/day (0.1/day, base 10). This value has been accepted and commonly used for years with reasonable results.

No measurements of deoxygenation rates for the streams under investigation are available. For this study a carbonaceous deoxygenation rate of 0.2/day was used. Field measurements of typical deoxygenation rates for streams in Iowa are needed to verify this value and would greatly improve the predictability of the modeling.

Information on nitrogenous deoxygenation rates is extremely limited, however, available information indicates that nitrification rates (when active nitrification does occur) are somewhat greater than carbonaceous oxidation rates. Therefore, a nitrogenous deoxygenation rate (K_n) of 0.3/day was selected for the study. Again, field measurements of typical nitrogenous deoxygenation rates in Iowa streams would greatly enhance the accuracy of the modeling effort.

Many formulations have been advanced to predict the reaeration rate constant, K_2. The particular formulation that was applied to the Upper Des Moines and Raccoon Subbasins was developed by Dougal et al. (2) for the Skunk River. The specific formulation is as follows:

$$K_2 = 11.5Q^{-0.0185}$$

where:

K_2 = Reaeration rate constant (base e).
Q = Stream flow, cfs.
Formulation applicable for flows less than 100 cfs.

Physical characteristics and low flow conditions are similar between the Skunk River Basin, and the Upper Des Moines and the Raccoon Subbasins. These streams have fairly wide channels and shallow depths under low flow conditions. The Dougal formulation was verified for the Skunk River under intensive field investigations.

All other modeling used the recently developed formulation of Tsivoglou and Wallace (3) adopted for determination of the reaeration rate constant. This formulation is based on the premise that the reaeration capacity of nontidal fresh water streams is directly related to the energy expended by the flowing water, which in turn is directly related to the change in water surface elevation.

The change in water surface elevation divided by the time of flow is the average rate of energy expenditure. This relationship is expressed by:

$$K_2 = 0.048 \left(\frac{h}{t}\right) \text{ @ } 20^{\circ}\text{C}$$

where:

K_2 = Reaeration rate.

h = Water surface elevation change in feet.

t = Time of flow in days.

Tsivoglou's equation was derived from actual measurement of stream reaeration rates by a new field tracer procedure in which a radioactive form of the noble gas krypton serves as a tracer for oxygen.

The reaeration rate predictive model has been verified for streams ranging in flow from 5 to 3,000 cfs. It can also be used to quite accurately predict reaeration effects of dams and waterfalls.

In development of Tsivoglou's procedure, other reaeration rate predictive formulas were compared with results obtained from the field tracer technique, but none appeared to predict stream reaeration rates as accurately as the Tsivoglou model.

Temperature corrections for the carbonaceous and nitrogenous deoxygenation rate constants and also the reaeration rate constants are performed within the computer model. The following equations define the specific temperature corrections used in the program:

$$K_{1(T)} = K_1(20) \times 1.047^{T-20}$$

$$K_{2(T)} = K_2(20) \times 1.024^{T-20}$$

$$K_{n(T)} = K_n(20) \times 0.058\ (T-0.16) \quad : \quad T>3^{\circ}C$$

$$K_n(T) = 0 \quad : \quad T\leq 3^{\circ}C$$

Where:

T = Water Temperature, °C

These temperature corrections for K_1 and K_2 are generally accepted formulations. Information on the effects of temperature on K_n is lacking. The formula given was derived from information on temperature effects on nitrification rates in biological treatment systems. The formula predicts nitrification rates of zero at $3^{\circ}C$ ($37^{\circ}F$) and below.

The principal factor affecting the solubility of oxygen is the water temperature. Dissolved oxygen saturation values at various temperatures are calculated as follows:

$$C_s = 24.89 - 0.426t + 0.0037t^2 - 0.00001335t^3$$

Where:

t = Water temperature, °F.

C_s = Saturation value for oxygen at temperature, t (°F), at standard pressure.

Stream Velocity Calculations

Stream velocities are important in determining reaeration rates and the downstream dispersion of pollutants. The computer model used, calculates velocity based on a variation of the Manning Formula for open channel flow. The Manning Formula for open channel flow is:

$$v = \frac{1.5R^{2/3}S^{1/2}}{n}$$

Where:

v = Velocity, fps.

R = Hydraulic radius, ft, = cross-sectional area/wetted perimeter which approximately equals the mean depth for rivers.

S = Channel Slope, ft/ft.

n = Roughness coefficient.

By multiplying both sides of the equation by the cross-sectional area, which is equal to the mean depth times the water surface width, and solving for the mean depth, the following relationship is obtained:

$$d = \left[\frac{QN}{1.5WS^{1/2}}\right]^{3/5}$$

Where:

d = Mean river depth, ft.

Q = Discharge, cfs.

W = Water surface width, ft.

S = Slope, ft/ft.

n = Roughness coefficient.

Once mean depths are calculated, velocities are determined from the relationship:

$$v = Q/A = Q/Wd$$

River slopes were obtained from existing profiles when available, but usually were taken from USGS topographic maps. Slopes obtained from USGS maps are rather generalized, and more accurate river profiles would greatly improve the accuracy of velocity determinations.

River widths and roughness coefficients were estimated from information obtained from field observations and flow and cross-sectional data at each USGS gauging station.

Stream velocities and depths are important in determining reaeration and the downstream dispersion of pollutants. The computer model uses depth and velocity estimates based on extrapolating known low flow data at stream gauging stations to other points along the stream. The extrapolation is a very rough approximation, but should be reasonably close over the average length of a stream. Again, field investigations to determine actual stream velocities and depths would improve the accuracy of the model.

Computer Input and Output Data

In order to calculate water quality at various points in the river, the river length to be modeled was divided into reaches. River characteristics such as mean widths, depths, velocities, deoxygenation and reaeration rate constants, and water temperatures were considered constant for each reach. The location of the reaches was set by one or more of the following:

1. A tributary.
2. A wastewater discharge.
3. A change in river characteristics, such as river width or slope.
4. A dam.

In order to calculate water quality characteritics at various points within each reach, the reaches were divided into segments called sections.

Actual data input into the computer program are as follows:

1. Initial river conditions such as flow and concentrations of ultimate carbonaceous BOD, ammonia nitrogen, and DO.

2. Uniform background flow contributions for each reach and concentrations of ultimate carbonaceous BOD, ammonia nitrogen, and DO in the ground water.
3. The number of reaches and for each reach the following:
    a. Length
    b. Number of sections
    c. Water temperature
    d. Channel Slope
    e. River width — Tsivoglou
    f. Roughness coefficient
    g. River Velocities — Dougal
    h. Deoxygenation rate constants
4. Wastewater or tributary inflows consisting of inflow rates, ultimate carbonaceous BOD ammonia nitrogen, and DO concentrations.

A flow chart of the steps in the computer program is shown in Figure IV-14. Following is a description of the calculations performed in each block of the flow chart after the required input data has been read in:

1. Stream Discharges - Discharges(cfs) are calculated at the beginning of each section by summing tributary and wastewater inflows along with incremental ground water inflows. The mean discharges for each reach are calculated for use in stream depth and velocity calculations.

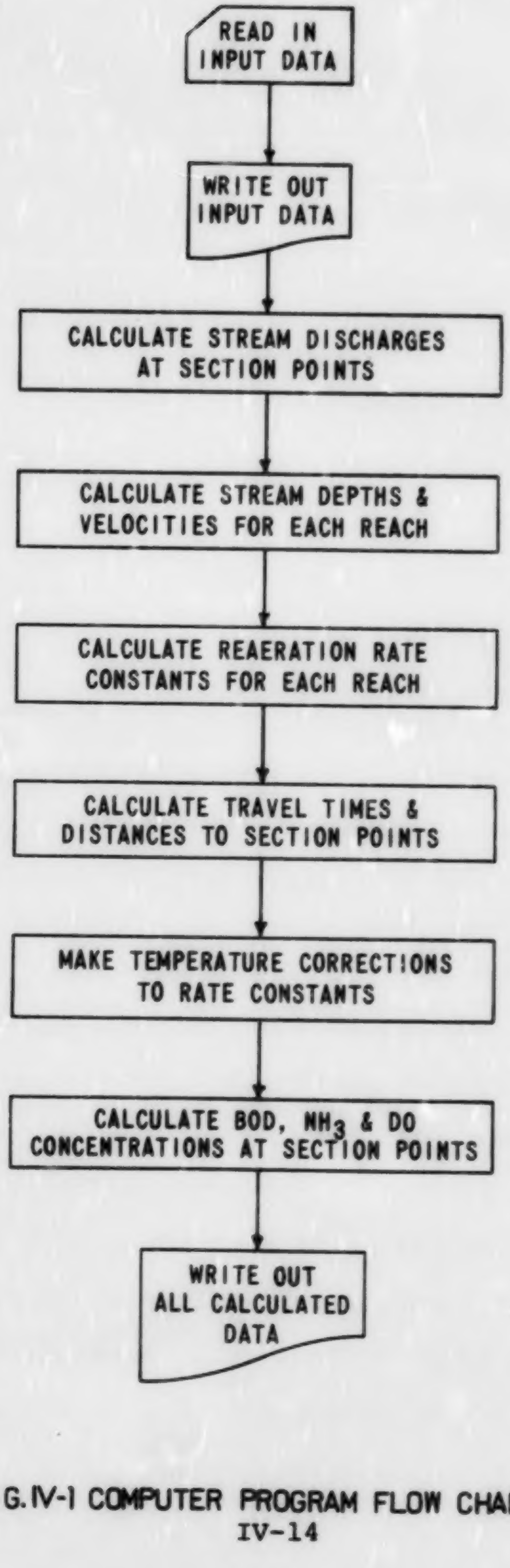

READ IN INPUT DATA
WRITE OUT INPUT DATA
CALCULATE STREAM DISCHARGES AT SECTION POINTS
CALCULATE STREAM DEPTHS & VELOCITIES FOR EACH REACH
CALCULATE REAERATION RATE CONSTANTS FOR EACH REACH
CALCULATE TRAVEL TIMES & DISTANCES TO SECTION POINTS
MAKE TEMPERATURE CORRECTIONS TO RATE CONSTANTS
CALCULATE BOD, NH_3 & DO CONCENTRATIONS AT SECTION POINTS
WRITE OUT ALL CALCULATED DATA

FIG. IV-1 COMPUTER PROGRAM FLOW CHART

2. Stream Depths and Velocities - Mean stream depths (feet) and velocities (fps) are calculated for each reach from a modification of Manning's formula for open channel flow using stream mean widths, roughness coefficients and discharges for each reach.
3. Reaeration Rate Constants - Using channel slope and stream velocity reaeration rate constants ($days^{-1}$) are calculated for each reach using Tsivoglou's formula. A correction factor for ice cover is included in the reaeration rate constant formulation.
4. Travel Time and Distances - Using stream velocity and reach and section lengths the time of travel (days) and distances (miles) are calculated for the start of each section. Mile zero and time zero are the start of Reach 2, or the beginning of the stream modeling effort.
5. Temperature Corrections - Using water temperature (°C) the deoxygenation and reaeration rate constants for each reach are corrected for temperature.
6. BOD, NH_3 and DO Concentrations - Calculations of these concentrations involves a number of steps depending on conditions encountered at each reach. Steps are as follows:
   a. Tributary inflow is checked to determine if it is zero or positive. If tributary inflow

is zero, initial values for BOD, NH_3 and DO are set equal to stream concentrations just upstream from the tributary. If tributary inflow is positive then new initial values for BOD, NH_3, and DO, after mixing of tributary and stream flows, are calculated.

b. The DO saturation concentration for the water temperature of the given reach and the initial DO deficit concentration for the reach are calculated. Since the DO saturation formula is based on ^{o}F the water temperature is converted to ^{o}F from ^{o}C.

c. Stream flow is assumed to consist of point source discharges, tributary inflow, and background (groundwater) contribution. Background contribution (cfs/mile) is checked to determine if it is negative, zero or positive. If groundwater inflow is negative (i.e., losing stream) or zero then BOD, NH_3, and DO concentrations are calculated at section points using the established formulas with initial conditions as calculated in steps (a) and (b).

   If the groundwater contribution is positive then BOD, NH_3, and DO are calculated as if each section is a separate reach, and groundwater contributions are treated the same as tributary discharges. BOD, etc., concentrations are determined at section points just before groundwater inflows. At each section new initial values are calculated from mixing of the stream flow with the incremental groundwater inflow, and the procedure is repeated for the next section. The values for BOD, etc., which are stored and printed out at section points, are the values after mixing with the groundwater flow. In most cases the incremental groundwater contribution is small enough that differences in concentrations before and after mixing are insignificant.

d. Each calculated DO concentration is checked to determine if it is negative, zero or positive. If the DO concentration is negative, it is set to zero. When the stream turns anaerobic the usual procedure is to continue use of the normal formula for prediction of DO deficits allowing the deficit to increase. This may or may not accurately predict the point at which the stream turns aerobic. Fortunately, waste load allocation studies are not concerned with zero stream DO concentrations, but in maintaining higher values such as 4 to 5 mg/l.

After calculations, computer output data consists of the following for each reach:

1. Mean river velocities.
2. Reaeration rate constants.
3. Temperature corrected reaeration and deoxygenation rate constants.
4. Saturation DO concentrations for the given temperature.

and the following at the beginning of every section within a reach:

1. Summation of the river miles evaluated.
2. Cumulative discharge.
3. Cumulative travel time in days.
4. Ammonia nitrogen concentrations.
5. Ultimate carbonaceous BOD concentrations.
6. Dissolved oxygen concentrations.
7. Dissolved oxygen deficits.

MODELING PROCEDURE

The bulk of the work in stream water quality modeling is the collection and interpretation of all available data describing the stream system to be modeled. This section describes procedures and data sources that may be used in stream modeling for waste load allocation work.

Wastewater Discharges - Required data for each discharger are flow rates and effluent characteristics such as BOD, NH_3-N and DO concentrations and temperature. The specific location and characteristics of some wastewater discharges are often unknown and should be determined from field trips and surveys.

River Miles - The first step in modeling a river system is determining the locations of all tributaries, wastewater dischargers, dams and other critical points along the river. The total length of the main channel of the river to be modeled must be established and river miles need to be located such that the location of tributaries, etc., can be determined to the nearest one-tenth of a mile. Often the U.S.G.S. or Corps of Engineers have located river miles, but in many instances these river miles are incorrect or do not properly add up. Experience has shown that it is best to start from the beginning with the best available base map and establish river miles by use of appropriate measuring techniques. The best maps to start with are

U.S.G.S. contour maps. These consist of section maps (scale: 1:250,000) and quadrangle maps (scale: 1:24,000). Section maps are usually available for a total state while quadrangle maps have not been made for many areas. Other maps such as state and county road maps can also be used to supplement the U.S.G.S. maps.

Field Reconnaissance - The precise location of wastewater dischargers is often impossible without field trips. A field trip along the length of river to be modeled is essential and should be done during the early phases of the modeling work. Data that can be easily collected during these trips are:

1. The precise location of wastewater discharges.
2. The location, condition, height and type of dams and the nature and approximate length of the pool created by the dam.
3. Approximate river widths at bridge crossings.
4. Approximate shape of channel cross sections.
5. Channel characteristics that will be an aid in determining channel roughness coefficients.

The field trip should be made, if possible, during flow conditions that represent the flows used in the modeling effort. Discharge information on the days of the field trip should be obtained from the U.S.G.S. Discharges observed during field trips are almost always greater than

7-day, 10-year low flows. Data such as river widths need to be extrapolated downward to represent 7-day, 10-year low flow conditions. Shapes of channel cross sections are an aid in this determination.

It is also recommended that photographs be taken at every access point to the river. Usually pictures should be taken looking both upstream and downstream. These photographs should be kept in a file with proper identification. They are a valuable reference in the modeling effort, as well as in future work.

River Channel Slopes - After river miles and locations are established the next step is determination of river channel slopes. During low flow it can be assumed that river channel slopes are essentially the same as the slope of the water surface and channel profiles can be used as representative of water surface slopes. In some cases profiles of the river have already been determined. This is usually done by the U.S. Army Corps of Engineers as part of work conducted prior to proposal or construction of flood control reservoirs. Without accurate profiles, river slopes can be determined from U.S.G.S. contour maps by locating the points where contour lines cross the river. Contour intervals on U.S.G.S. section maps are only 50 feet which makes river slopes determined in this fashion only averages for the distance of the river between contour intervals. Often, this is the only information available and is the best method of slope determination without an extensive field survey.

River Widths and Roughness Coefficients - Estimation of river widths and roughness coefficients can be done after the field reconnaissance. Roughness coefficients can be estimated using tables and techniques in hydraulic texts and handbooks. One of the best references is Chow (*Open-Channel Hydraulics*, McGraw-Hill).

The variation of river widths with discharges can often be determined from data at U.S.G.S. gauging stations. The U.S.G.S. periodically calibrates each gauge. The results from these calibrations are available on U.S.G.S. form 9-207 and includes widths, cross-sectional area, mean velocities and discharges. Reasonably accurate estimations of river widths at the desired discharge can usually be made with this gauging station information along with river widths measured during field trips.

Discharges - Determination of flow conditions throughout the river system to be modeled requires all available data from U.S.G.S. flow measuring stations as well as flow rates of all wastewater discharges. River flows need to be allocated among tributary, groundwater and wastewater inflows. If 7-day, 10-year low flows are used as the modeling basis, they can be determined from a statistical analysis of the flow records at each of the gauging stations in the river system. Often low flows have already been determined for areas or states (e.g. Iowa Natural Resources Council, *Low-Flow Characteristics of Iowa Streams Through 1966, Bulletin No. 10*, 1970). The flows at gauging stations must be allocated to tributaries based on drainage areas. Tributary drainage areas may be available from existing publications (e.g., Larimer, O. J., "Drainage Areas of Iowa Streams," Iowa Highway Research Bulletin No. 7, 1957) or they can be determined from U.S.G.S contour maps.

A summation of tributary inflows and wastewater discharges often is less than the gauged flow. The difference is usually distributed along the main channel of the river as a uniform inflow in terms of cfs per mile of river length. If the gauged flow is less than the summation of tributary and wastewater inflows then it is possible to allot a uniform outflow to the main river channel.

Tributary and Groundwater Quality - Values for BOD, NH_3-N and DO of tributary and groundwater inflow are required for stream modeling. Often a main tributary to the stream being modeled has also been modeled. In this case the water quality of the tributary just before discharge into the main stream (as determined by the model) may be used. If the tributary is small and has several wastewater discharges, hand calculations can be done to determine its water quality just before entering the main stream.

If the tributary is free of wastewater discharges water quality can be assumed to be good. Ultimate BOD's should be below 5 mg/l, NH_3-N concentrations less than 0.1 mg/l and DO's near saturation.

Groundwater should be of high quality. One can generally assume BOD's below 2 mg/l and NH_3-N at 0 mg/l. Groundwater DO's may be quite low depending on how it enters the stream. If it is subsurface flow, DO's may be close to zero. Groundwater DO's of 2 mg/l have been used in waste load allocation work in Iowa.

Rate Constants - Reaeration rate constants are usually determined from one of many available predictive formulas. The one used in the computer programs is after Tsivoglou.

Carbonaceous and nitrogenous deoxygenation rate constants are best determined experimentally for a specific wastewater effluent and specific stream. Otherwise "typical" values from similar streams may be used. In most cases the carbonaceous deoxygenation rate constant, K_1 will not be less than 0.2 per day (20° C). Values as high as 2 per day (20° C) have been reported in the literature. It appears that most streams will have values of K_1 between 0.2 and 1.0/day at 20° C.

Less information is available on the nitrogenous deoxygenation rate constants or nitrification rate in streams. Experimental work in Illinois (State of Illinois, Environmental Protection Agency, Guidelines for Granting of Exemptions from Rule 404(C) and 404(F) Effluent Standards, Oct., 1974) determined that the nitrogenous deoxygenation rate constant, K_n, ranged from 0.25 to 0.37 per day with an average value of 0.29 per day at 20° C.

Dams and Impoundments - The damming of a stream creates special problems in water quality modeling. For modeling purposes dams and the resulting impoundment can be put into one of two classifications.

1. Large dams that backup rather extensive impoundments. Flow through the impoundment is not "plug flow" and inflow may be dispersed in a variety of vertical and horizontal directions.
2. Low-head dams which essentially make the river channel wider and deeper for a maximum distance of several miles. Flow through the impoundment is primarily "plug flow."

Class 1 dams and impoundments cannot, with existing technology, be modeled to predict water quality. The modeling effort should be stopped at the beginning of the impoundment and started again below the dam. Water quality below the dam can be estimated from knowledge of the size of the impoundment and the method of water withdrawal. Water taken from the lower levels of an impoundment during periods of summer stratification may be low in DO. If water flows over a spillway or an overflow weir it may be close to the DO saturation point. One can expect the BOD and NH_3-N concentrations in the discharge from large impoundments to be low unless the impoundment is highly eutrophic.

Class 2 dams and impoundments can be modeled by treating the impoundment as an enlarged or slower moving section of the river. The length of the pool backed up by the dam may be divided into one or more reaches. Widths can be approximated from field observations. Slopes are taken as the water surface elevation and are quite small, generally elevation drops off no more than a foot over the length of the pool.

The dam may be treated as a reach 0.001 miles or 5.28 feet in length. The slope of this reach then becomes the dam height divided by 5.28 feet. The only water quality parameter that is significantly affected through the dam reach is the DO. Tsivoglou's reaeration rate constant prediction formula can be used to quite effectively predict reaeration over a dam. The equation for change in the DO deficit with time is:

$$D_t = D_o e^{-K_2 t}$$

Where:

D_t = DO deficit at time, t.

D_o = DO deficit at time zero.

K_2 = Reaeration rate constant.

Tsivoglou's reaeration rate constant predictive equation is:

$$K_2 = \frac{c \Delta H}{t}$$

Where:

c = escape coefficient.

H = change in elevation in time, t.

Substituting into the DO deficit equation one obtains:

$$D_o = D_o e \ \frac{-c\Delta H}{t}$$

With a dam 10 feet high and c = 0.048/ft the ratio of D_t/D_o is 0.62 or the deficit at time, t, is 62 percent of the deficit at time zero. This is a DO deficit recovery of 38 percent.

Winter Conditions - Often the most critical period for maintaining water quality standards is winter low-flow periods instead of summer. Rates of deoxygenation are greatly reduced at the low temperatures, but ice cover also greatly reduces reaeration so that DO levels may be critical. Nitrification does not occur at freezing temperatures. Consequently, ammonia concentrations buildup in streams and may reach levels toxic to aquatic life.

During winter periods reaeration rates need to be reduced in proportion to the extent of ice cover. Even with 100 percent ice cover a small amount of reaeration undoubtedly takes place. In the waste load allocations reaeration rates were reduced in direct proportion to the ice cover. At an ice cover of 100 percent reaeration rates were reduced by 95 percent, at an ice cover of 95 percent rates were reduced by 90 percent and so forth. Research is needed on the effects of ice cover on stream reaeration rates, in order to more precisely define the applicable reduction factor.

WASTE LOAD ALLOCATIONS

Using the computer, waste load allocations required for dischargers to meet State Water Quality Standards within the basin were determined. Waste load allocation analyses were performed assuming projected 1990 wastewater discharges at the 7-day 1-in-10 year low flow under both summer and winter conditions. Analysis was performed on streams classified either A, B, or C with existing wastewater discharges. Some specific assumptions and considerations that went into the analysis are discussed below.

From the two waste load allocations (winter and summer), one final allocation, the more stringent, is selected for each discharger.

Assumptions

In order to define waste load allocations for dischargers within the state, specific assumptions are required. Identification of the major items required to evaluate and determine waste load allocations are identified in the following list.

1. The major objective of the present investigation is to satisfy Iowa Water Quality Standards with future

effluent discharges. Determinations of allowable effluent concentrations was based upon varying the effluent quality from point source dischargers until the model maintained dissolved oxygen concentrations above 5.0 mg/l and ammonia nitrogen concentrations below 2.0 mg/l in all stream sections designated as water quality limited at the 7-day 1-in-10 year low flow. Because National Pollutant Discharge Elimination System (NPDES) permits are currently requiring dischargers with waste stabilization ponds to have controlled discharge capabilities, no discharge from waste stabilization pond treatment facilities was assumed at low flow conditions.

2. Definition of 7-day 1-in-10 year low flow was required for each stream modeled. For those streams where the low flow exceeded the total present average daily wastewater discharges from all entities within their respective basin, the difference between the 7-day, 1-in-10 year low flow and the wastewater discharges was assumed to be the result of groundwater inflow to the stream. This amount of groundwater inflow was assumed to remain constant over the planning period. Since most wastewater discharges will increase during this time period, the 7-day 1-in-10 year low flow in 1990

is greater by the amount of this increase. Groundwater contribution to the stream flow was distributed throughout the basin in proportion to the drainage area contribution to the stream along the length of its channel. Values of 4.0 mg/l, BOD_5, 0.0 mg/l ammonia nitrogen, and 2.0 mg/l dissolved oxygen concentration were assumed as the water quality of the groundwater contribution.

3. Ultimate carbonaceous BOD was assumed to be 1.5 times the BOD_5.
4. Average stream temperature was assumed to be approximately $26^\circ C$ ($79^\circ F$) and $1^\circ C$ ($34^\circ F$) during summer and winter low flow conditions, respectively.
5. In order that the reaeration rate constant be applicable to wintertime ice conditions, the amount of ice cover on the stream was estimated. It was assumed that the effective amount of reaeration should be inversely proportional to the percentage of ice cover. The winter reaeration rate constant for each reach of the stream was then determined by multiplying the temperature corrected rate constant by the fraction of open water in the reach. Ice cover estimates were based upon general climatological conditions for the basin and upon personal observa-

tions. Complete ice cover was assumed to be non-coincidental with the 7-day 1-in-10 year low flow. The percent of ice cover used for winter conditions in the computer analysis ranged from 90 percent to 95 percent.

6. After determining the sensitivity of the model to the deoxygenation rate constant, the values of 0.2/day and 0.3/day were selected for $K_1(20)$ and $K_n(20)$, respectively.
7. Since no data is available describing effluent dissolved oxygen concentrations or temperatures, the following values were assumed for each class of wastewater dischargers.

	Summer			Winter		
Discharge From	DO (mg/l)	Temperature (°C)	(°F)	DO (mg/l)	Temperature (°C)	(°F)
Trickling Filter	3.0	20	68	4.0	9	48
Activated Sludge	3.0	20	68	4.0	9	48
Industrial Plant	Each Discharge Handled Individually					

8. From analysis of available effluent data it has been assumed that a well operated and maintained secondary treatment plant should be able to achieve 10 mg/l or 15 mg/l of ammonia nitrogen under summer or winter conditions, respectively.

9. Best practicable waste treatment technology effluent limitations described by EPA guidelines were used for industrial dischargers when available and sufficient. Otherwise, the actual allowable waste load required to meet stream standards was determined and identified as the waste load allocation for that discharger.

10. Water quality of tributaries (without wastewater sources) discharging to the streams being modeled was assumed to have saturated dissolved oxygen concentrations, an ultimate BOD concentration of 6.0 mg/l, and an ammonia nitrogen concentration of 0.0 mg/l in the summer and 0.5 mg/l in the winter.

11. Mixing of waste and tributary flows with the main body of water were assumed to be complete and instantaneous.

12. Uniform lateral and longitudinal dispersion (plug flow) was assumed for the stream constituents as they move down stream.

REFERENCES

1. Streeter, H. W., and Phelps, E. B. "A study of the Pollution and Natural Purification of the Ohio River. III., Factors concerned in the Oxidation and Reaeration." Public Health Bulletin No. 146, U.S. Public Health Service, Washington, D.C. (1925)

2. Dougal, Baumann, and Timmons, "Physical and Economic Factors Associated with the Establishment of Stream Quality Standards," Volume No. 2, March, 1970.

3. Tsivoglou, E. C., and Wallace, J. R., "Characterization of Stream Reaeration Capacity," U.S. Environmental Protection Agency. EPA-R3-72-012, October, 1972.

CHAPTER V - TREATMENT ALTERNATIVES

EXISTING FACILITIES

In recognition of the fact that many existing wastewater treatment facilities for municipalities and industries will have to be upgraded in order to meet established water quality standards it becomes necessary to identify what can be done to achieve a consistently acceptable discharge. Most municipal wastewater treatment facilities in Iowa presently incorporate either trickling filters or waste stabilization ponds (i.e. lagoon systems) as the means to achieve secondary treatment. Waste stabilization ponds have been used extensively since 1959 because of their low capital costs, low operational costs, simplicity of operation, and availability of acceptable land areas. Trickling filters have historically offered many advantages for the intermediate size communities because of their relatively low construction and operation costs and the simplicity of operation.

The trickling filter plants generally report effluent BOD_5 values of 30 mg/l or less during the warm summer months. During cold weather operations (November through March) treatment efficiency declines and effluent BOD_5 values of 40 to 70 mg/l are common. Waste stabilization ponds follow a similar cycle, with effluent BOD_5 values of 25 mg/l or less during summer operating conditions and higher values during the winter months. Although effluent suspended solids concentrations are not reported for lagoon systems, values may be expected to increase substantially during the summer periods when algae reach peak activity.

There are many processes which are available for wastewater treatment. Of the two following subsections the first will present processes or techniques which are available for the upgrading of existing facilities, and the second subsection will present processes which will provide for advanced wastewater treatment.

FACILITY UPGRADING TECHNIQUES

Technology in the field of wastewater treatment in the past decade has provided many innovative upgrading procedures to meet deficiencies in existing processes. Various research projects sponsored by EPA have resulted in a better understanding of various unit processes. In addition, new types of equipment for wastewater treatment have enlarged the range of alternatives available for consideration in upgrading treatment plants.

It has long been recognized that the performance of a wastewater treatment plant is affected by variations in the influent flow. Equilization of extreme flows can dampen the fluctuations in loading to a plant.

Various processes and process equipment are being marketed and successfully used to increase removal in primary and secondary clarifiers. They include the use of chemical coagulation, peripheral-feed clarifiers, and inclined-tube settlers. These procedures, in many cases, have the effect of maintaining good solids removal while maximizing the hydraulic throughput in the existing facilities. Chemical addition in primary and secondary clarifiers can increase solids capture and BOD removal. In addition, several types of screening devices are available as possible substitutes for primary clarification.

Several modifications of the conventional activated sludge process, including step aeration, contact stabilization, and complete mixing, have been adequately studied and have been used to upgrade various treatment plants. A most significant development in the activated sludge treatment process came with the full-scale demonstration of the feasibility and effectiveness of using oxygen aeration as a substitute for air aeration. Plants using oxygen aeration are now being designed or under construction in Iowa. These include plants in Dubuque, Muscatine, Ft. Madison and Cedar Rapids.

Another method of upgrading an overloaded secondary plant is to provide additional treatment ahead of the existing biological treatment facilities. The use of plastic media trickling filters should be considered when roughing treatment is indicated. Plastic media filters have been successfully used as roughing filters in industrial wastewater treatment, and show potential for use in the future for the upgrading of municipal treatment plants.

Nitrification during summer months may be accomplished through modifications to the existing treatment units, such as addition of chemicals to the primary clarifier to decrease the organic loading to existing aeration units. However, dependable year-round nitrification will require a two-stage biological treatment system.

Inadequate digestion and sludge handling facilities often adversely affect the overall treatment plant operation. The return of supernatant or filtrate from thickening or dewatering units to the head of the plant can impose high oxygen demands on the system and add substantial amounts of fine solids which are difficult to remove in the secondary clarifier. The high concentration of nutrients and organics in such streams and the periodic nature of the return flow often necessitate separate treatment, especially when nutrient removal is a consideration.

Various sludge-handling developments which have been successful are: 1) high-rate anaerobic digestion; 2) aerobic digestion; 3) thickening of sludge prior to digestion to increase the capacity of existing digesters; 4) the use of chemicals to improve thickening and dewatering of sludges; and 5) the use of heat treatment processes for the disposal of sludges. The use of aerobic digestion is likely to alleviate many of the operational problems associated with the anaerobic treatment of sludges.

Flow Equalization

Municipal and industrial wastewater flows exhibit a cyclic nature, in terms of volume and strength. While the concept of flow equalization has been employed in the field of water supply and in the treatment of some industrial wastes, it has not been widely accepted in the municipal pollution control field. Anticipated problems with solids settling, odor, and septicity can be cited as the major factors limiting its use.

Recently, interest in flow equalization for municipal treatment has increased due to the advent of stricter water quality standards, the elimination of plant bypassing, and the increased removal efficiencies that are possible when biological or chemical treatment processes are operated at or near steady-state conditions.

There are two major objectives in the design of flow equalization basins. The first of these is simply to dampen the diurnal flow variations that normally exist in typical municipal wastewater collection systems, and thus achieve a constant or nearly constant flow rate through the downstream treatment processes. In this type of system, little consideration is given to controlling the concentration changes that take place during storage. The major design factors are supplying enough air to keep the basin aerobic and providing adequate mixing to prevent solids deposition. Consideration should be given to locating equalization basins at the treatment plant site and/or at strategic upstream locations in the tributary collection system. The upstream locations may offer the added advantage of relieving trunk sewer overload during peak flow periods.

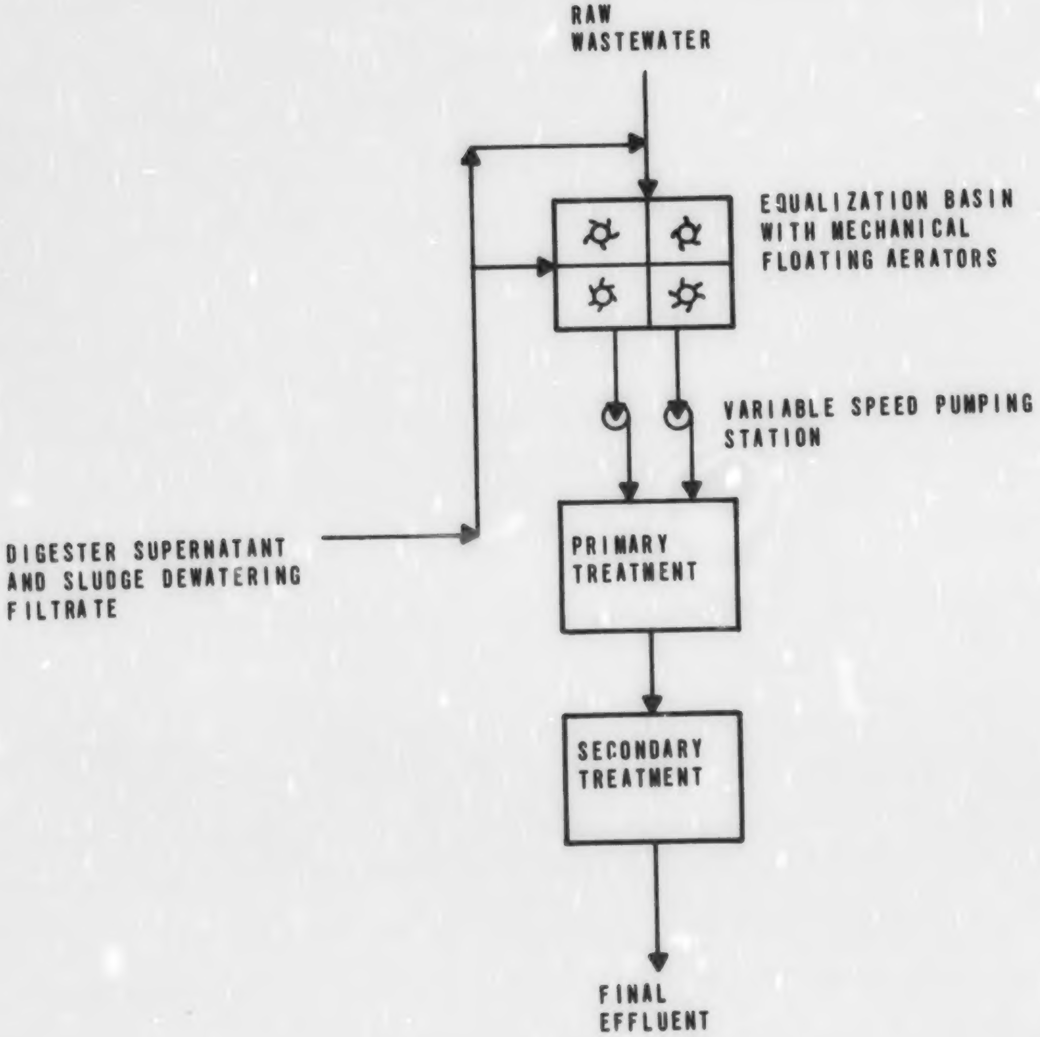
The second objective of flow equalization is to provide the capacity to distribute shock loads of toxic or treatment-inhibiting substances over a reasonable period of time to prevent system failure and to minimize the periodic discharge of harmful contaminants to the receiving stream or surface impoundment. The measurement or estimation of time-dependent concentration profiles and flow-through curve is normally used to analyze the flow characteristics of these systems for determining the effects of tank geometry, effluent weir placement, and mixing regime on changes in contaminant concentrations through the basin.

In all cases, the added costs of flow equalization must be measured against the reduction in downstream process costs and the increased efficiencies that can be achieved by operating these processes under relatively constant loading conditions.

A typical equalization flow schematic is shown in Figure V-1. The flow enters the equalization basin by gravity, and the basin contents are pumped to the primary treatment units using continuous-flow, variable-speed pumps. The maximum pumping capacity of the equalization pump station should be sufficient to handle the maximum flow expected, even though

FIGURE V-1

SCHEMATIC FLOW DIAGRAM OF EQUALIZATION FACILITIES(1)


RAW WASTEWATER
EQUALIZATION BASIN WITH MECHANICAL FLOATING AERATORS
VARIABLE SPEED PUMPING STATION
DIGESTER SUPERNATANT AND SLUDGE DEWATERING FILTRATE
PRIMARY TREATMENT
SECONDARY TREATMENT
FINAL EFFLUENT

the equalization basin may be designed to equalize a somewhat smaller flow.

Trickling Filter Techniques

The introduction of synthetic media for trickling filters has extended the range of hydraulic and organic loading well beyond the range of stone media. Table V-1 presents a comparison of physical properties of various types of trickling filter media. Two properties which are of interest are specific surface area and percent of void space. Greater surface areas permit a larger mass of biological slimes per unit volume, while increased void space allows for higher hydraulic loadings.

TABLE V-1

COMPARATIVE PHYSICAL PROPERTIES OF TRICKLING FILTER MEDIA

Packing	Nominal Size inches	Units per cu.ft.	Unit Weight lbs./cu.ft.	Specific Surface Area sq.ft.cu.ft.	Void Space percent
Plastic Media	20 x 48	2-3	2-6	25-30	94-97
Del-pak Redwood Media	47½x47½x35¼	-	10.3	14	-
Granite	1-3	-	90	19	46
Granite	4	-	-	13	60
Blast Furnace Slag	2-3	51	68	20	49

Most low-rate trickling filters are designed with depths ranging from 5 to 7 feet, while high-rate filters are designed with depths of 3 to 6 feet. The relatively deep low-rate filters improve the nitrification potential.

The treatment efficiency of a synthetic media trickling filter is much more responsive to variations in depth than a stone media trickling filter. For this reason, the depth selection for a super-rate filter is a major design parameter.

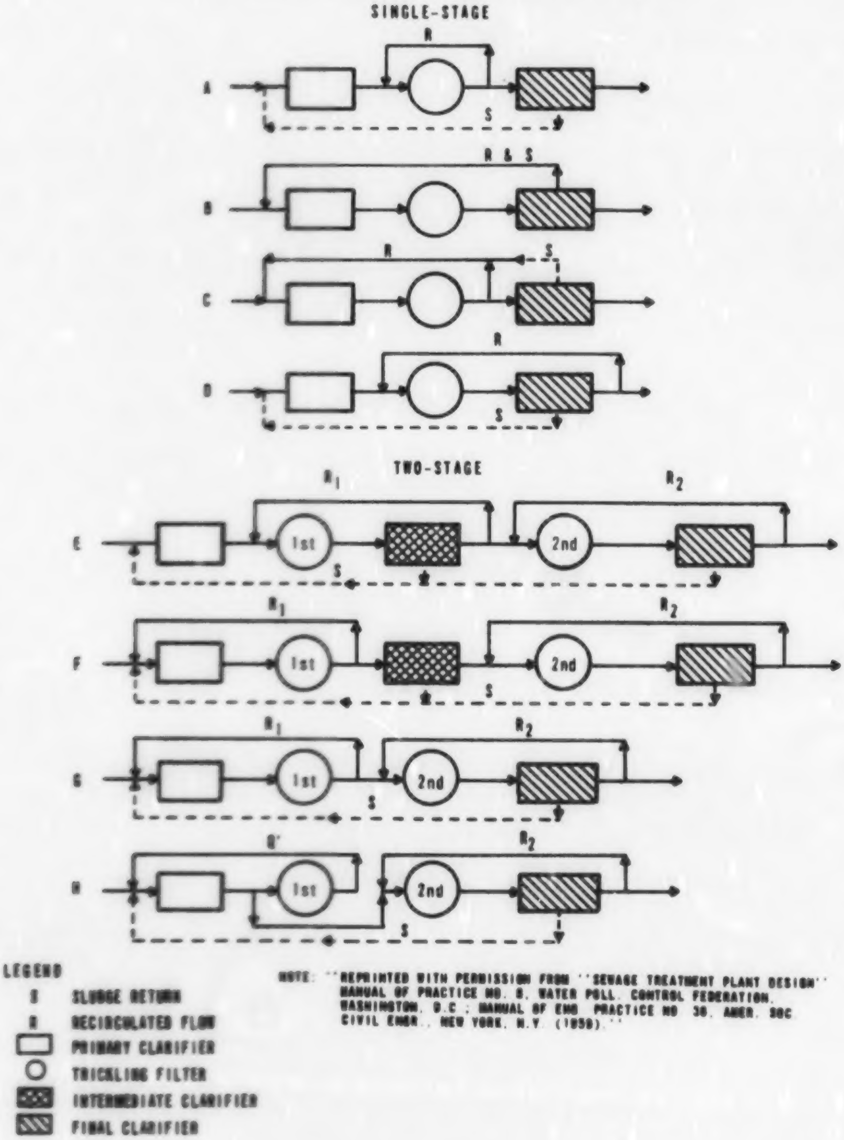
The practice of effluent recirculation can be used to improve the efficiency and operation of stone media trickling filters. For example, it can minimize the operational problems associated with intermittent dosing of low-rate trickling filters. Recirculation ratios of 0.5 to 4.0 have been used in high-rate filters.

There are many possible flow configurations which may be used with a single or two-stage high-rate trickling filter plant. Some of the more common flow diagrams which have been presented in the Water Pollution Control Federation's Sewage Treatment Plant Design Manual (MOP No. 8) have been included in Figure V-2.

Many trickling filter plants may be upgraded to relieve hydraulic and/or organic overloading by any one of the following three general procedures:

1. Upgrading an existing single-stage filter to adequately handle an increased load, either organic or hydraulic.
2. Upgrading a single-stage filter to a two-stage biological system.
3. Upgrading an existing two-stage trickling filter to a multiple biological system.

FIGURE V-2
COMMON FLOW DIAGRAMS FOR SINGLE AND TWO-STAGE HIGH-RATE TRICKLING FILTERS (1)


SINGLE-STAGE
A
R
S
B
R & S
C
R
S
D
R
S
TWO-STAGE
E
R_1
1st
S
2nd
R_2
F
R_1
1st
S
2nd
R_2
G
R_1
1st
S
2nd
R_2
H
R'
1st
S
2nd
R_2
LEGEND
S SLUDGE RETURN
R RECIRCULATED FLOW
▭ PRIMARY CLARIFIER
○ TRICKLING FILTER
▩ INTERMEDIATE CLARIFIER
▨ FINAL CLARIFIER

NOTE: ''REPRINTED WITH PERMISSION FROM ''SEWAGE TREATMENT PLANT DESIGN'' MANUAL OF PRACTICE NO. 8, WATER POLL. CONTROL FEDERATION, WASHINGTON, D.C.; MANUAL OF ENG. PRACTICE NO. 36, AMER. SOC CIVIL ENGR., NEW YORK, N.Y. (1959).''

Activated Sludge Techniques

The conventional activated sludge process as originally developed has undergone significant changes, primarily due to a better understanding of the theory involved and to the experience accumulated over the years in successful operation of the process.

Historically, the activated sludge process has been used in larger cities, where the ratio of the river assimilative capacity to waste load is small. In the past decade, there has been a trend towards its use by smaller communities to meet the more stringent effluent quality requirements.

Existing overloaded conventional activated sludge plants pose a problem to the maintenance of established water quality standards. Various modifications of the conventional process developed over the years permit reduced detention time in the aeration tanks.

Basically, the activated sludge process uses microorganisms in suspension to oxidize soluble and colloidal organics to CO_2 and H_2O in the presence of molecular oxygen. During the oxidation process, a portion of the organic material is synthesized into new cells. A part of the synthesized cells then undergoes auto-oxidation in the aeration tanks, the remainder forming excess sludge. Oxygen is required in the process to support the oxidation and synthesis reactions. In order to operate the process on a continuous basis, the solids generated must be separated in a clarifier for recycle to the aeration tank, with the excess sludge from the clarifiers being withdrawn for further handling and disposal.

In recent years there has been additional development and use of various activated sludge modifications, such as the following:

1. step aeration,
2. contact stabilization,
3. complete-mix,
4. two stage activated sludge,
5. oxygen aeration.

Each of these activated sludge modifications can be used to increase the overall efficiency of the conventional activated sludge plant or to increase the organic and hydraulic capacity of an existing treatment facility.

Clarification and Chemical Treatment Techniques

Improved solids separation in primary and secondary clarifiers, either by operational changes or by addition of chemicals, is usually accompanied by concurrent reductions in BOD values in the overflow. Therefore, improvements in the clarification process can be advantageously used to meet specific treatment requirements, particularly where the treatment plants are experiencing hydraulic and organic overloads. The solids separation process can be improved by adding additional clarification area, by chemical treatment of wastewaters, or by use of more efficient settling devices.

Increased solids separation in primary clarifiers has the following advantages in addition to increasing the hydraulic capacity:

1. An increase in quantity of primary sludge produced (which can be more readily thickened and dewatered than secondary sludge).
2. A decrease in quantity of secondary sludge produced.
3. A decrease in organic loading to secondary treatment process units.

The primary clarifier performance significantly influences the extent of secondary treatment required and, in most cases, affects the overall effluent quality of existing treatment plants. Also, since clarification is usually the most economical way to remove suspended and colloidal pollutants every effort should be made to improve the primary clarification process before additional facilities are considered.

At first, chemicals were used to improve the efficiency of primary clarification systems. Later, when these systems were followed by secondary treatment processes, the practice of adding chemicals to upgrade primary treatment became unnecessary. However, the technique of adding chemicals to the primary clarifier is still an effective upgrading procedure for a secondary plant when the following conditions exist:

1. Wastewater flow is intermittent or varies greatly.
2. Space available for additional clarification facilities is limited.

3. Industrial wastes that would interfere with biological treatment are present.
4. Plant is hydraulically and/or organically overloaded.
5. Improvements in existing treatment performance are required as an interim measure before the addition of new facilities.

The chemicals commonly used in wastewater treatment are the salts of iron and aluminum lime, and synthetic organic polyelectrolytes. The iron (ferrous and ferric) and aluminum salts (sodium aluminate or alum) react with the alkalinity and soluble orthophosphate in wastewater to form precipitates of the respective metallic hydroxides or phosphates. In addition, they destabilize the colloidal particles that would otherwise remain in suspension. These precipitates, along with the destabilized colloids, flocculate and settle readily in a clarifier.

Little information has been generated regarding the periodic addition of chemicals to the primary clarifier for controlling peak organic or hydraulic loads. This approach, while not always applicable, can frequently be used to maintain system stability during temporary overload.

Use of Tube Settlers

A new device called a tube settler, which employes the use of trays or tubes in the existing clarifiers, has recently become available. Tube settlers (of various lengths) are usually installed in modules at an angle to the horizontal, and are made of a light-weight, durable material. A typical inclined-tube settler module is shown in Figure V-3. Figure V-4 shows a typical clarifier cross-section with the tube settler modules installed. Even though the tube settlers can be used at any angle of inclination, an angle of 60 degrees is recommended, for self-cleaning purposes.

Tube settlers have been used in primary and secondary clarifiers to improve performance as well as to increase throughput in existing clarifiers. Several plant-scale installations of tube settlers in primary and secondary clarifiers indicate that the overflow rates in primary clarifiers can be increased to 5,000 gpd/sq. ft. while producing the same quality effluent as the control unit without the settlers. Tube settlers enhance the ability to capture settleable solids at high overflow rates because the depth of settling has been reduced to a few inches in the tube. It should be realized that tube settlers do not improve the efficiency of primary clarifiers that are already achieving very high (40-60 percent) removals of suspended solids. Moreover, tube settlers will neither remove colloidal solids that remain in suspension nor induce additional coagulation to effect added particle removal.

FIGURE V-3

INCLINED TUBE SETTLER MODULE (1)

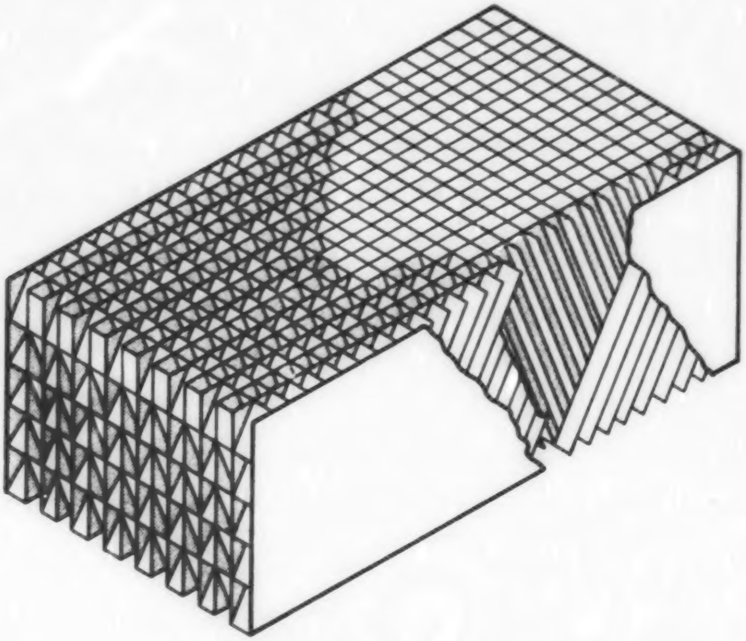
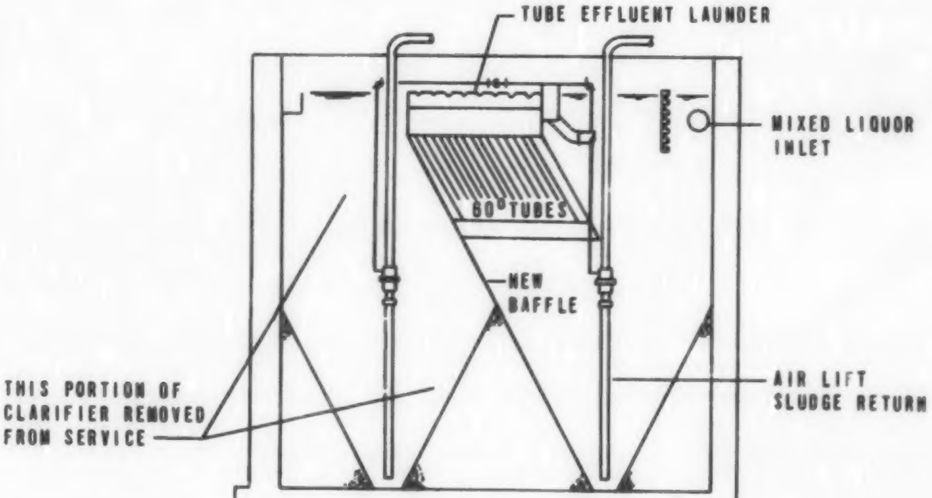


FIGURE V-4

INSTALLATION OF TUBE SETTLERS AT THE WICKAM, PENNSYLVANIA SEWAGE TREATMENT PLANT


TUBE EFFLUENT LAUNDER
MIXED LIQUOR INLET
60° TUBES
NEW BAFFLE
THIS PORTION OF CLARIFIER REMOVED FROM SERVICE
AIR LIFT SLUDGE RETURN

ADVANCED TREATMENT PROCESSES

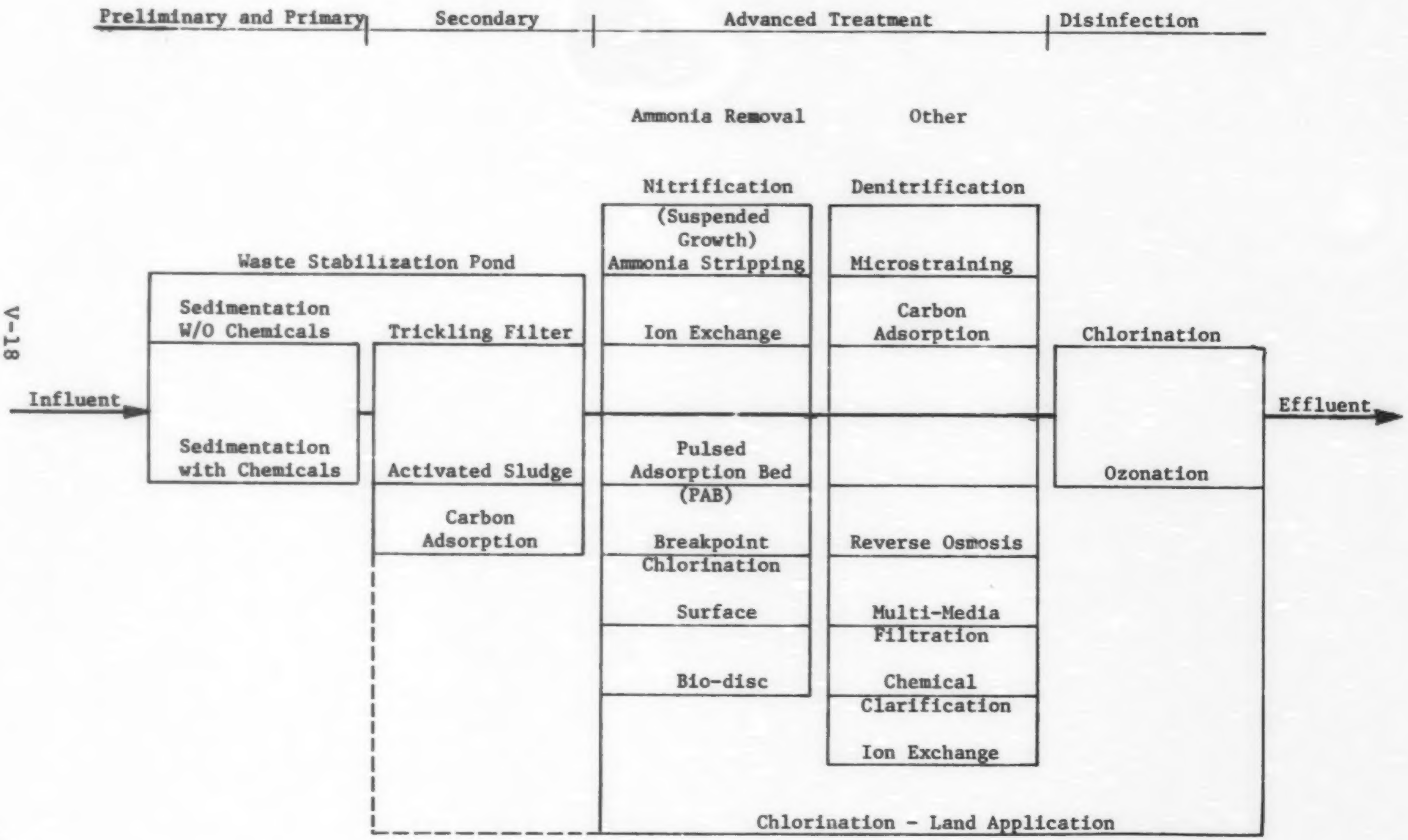
In addition to the various techniques and modifications available for improved effluent quality, numerous process combinations are available for advance treatment of municipal wastewater. Figure V-5 presents a variety of conventional and advanced wastewater treatment processes capable of removing various constituents and satisfying specific effluent requirements.

Although each process is capable of removing portions of the BOD_5 and ammonia concentrations in municipal wastewater, reverse osmosis, granual carbon absorption, denitrification, and chemical clarification have limited applicability in the study area. Reverse osmosis and granular carbon adsorption can reduce soluble BOD concentrations to extremely low values. Nevertheless, the relatively high unit cost of treatment, combined with the required preliminary treatment processes, eliminates these two alternatives from further consideration. The DEQ has no nitrate or phosphate stream standard limitations, except in those areas designated as Class C waters. Since denitrification facilities and lime clarification are primarily associated with removing nitrate and phosphate, respectively, no further discussion of these alternatives is presented.

Conversion of ammonia nitrogen to nitrate nitrogen is a major consideration for many streams in Iowa. Specific discussion relating to advanced treatment processes does not include ammonia stripping and selective ion exchange

FIGURE V-5

WASTEWATER TREATMENT ALTERNATIVES


Preliminary and Primary
Secondary
Advanced Treatment
Disinfection
Ammonia Removal
Other
Nitrification
Denitrification
Waste Stabilization Pond
Influent
Sedimentation W/O Chemicals
Sedimentation with Chemicals
Trickling Filter
Activated Sludge
Carbon Adsorption
(Suspended Growth) Ammonia Stripping
Ion Exchange
Pulsed Adsorption Bed (PAB)
Breakpoint Chlorination
Surface
Bio-disc
Microstraining
Carbon Adsorption
Reverse Osmosis
Multi-Media Filtration
Chemical Clarification
Ion Exchange
Chlorination
Ozonation
Effluent
Chlorination - Land Application

for the following reasons:

1. Ammonia stripping - Ammonia can be released to the atmosphere by passing wastewater through a stripping tower after adjustment to a pH of approximately 11.5. However, several problems associated with this process make use impractical for most areas of Iowa:
    a. The rates of the chemical reactions are temperature dependent (efficiency of ammonia removal is reduced approximately 40 to 60 percent when the wastewater temperature falls below 10 to 12 degrees F, (-12.2 to 11.1 degrees C). Therefore, winter weather in Iowa is too severe for economical year-round operation.
    b. Because of the high pH of the wastewater, calcium carbonate scale forms readily on the closely packed media of the stripping tower and must be removed frequently by acid washing or mechanical scrubbing.
    c. Ammonia released to the atmosphere is readily soluble in water and may be returned to exposed water surfaces in the immediate vicinity of the tower.

2. Selective ion exchange - The exchange of ammonium ions on clinoptilolite, a natural zeolite, is capable of a high ammonia removal efficiency. However, operating experience at wastewater treatment

facilities is very limited. Specific problems with use of this process are as follows:

a. Clinoptilolite is relatively expensive.
b. In addition to the complexity of operation, exchange resins are plagued by resin fouling and plugging during continued operation.
c. Disposal of the regeneration wastewater requires additional treatment considerations.

The remaining processes identified on Figure V-5 are discussed in terms of advantages and disadvantages to satisfy the designated treatment levels. Specific factors which must be considered in determining applicability of a unit process to an existing treatment facility are discussed. Combinations included in this section are capable of obtaining required effluent limits for raw municipal wastewaters containing approximately 200 mg/l BOD_5, 230 mg/l suspended solids, and 40 mg/l ammonia nitrogen.

Although these discussions may be used as a guide to alternative processes, definite selection of a treatment alternative is not possible. Additional detailed investigation during preliminary facility planning is required to define the most cost-effective solution for a specific location.

Microstraining

Microstraining has application in effluent polishing chiefly as a method of removing additional suspended solids (and their associated BOD) from wastewater treatment plant effluents. A typical unit is shown in Figure V-6. The microstrainer consists of a rotating drum with a peripheral screen. Influent wastewater enters the drum internally and passes radially outward through the screen, with deposition of solids on the inner surface of the drum screen. At the top of the drum pressure jets remove the deposited solids. This backwash water is then collected and returned to the head of the plant.

The screens employed in microstraining have extremely small openings and are made from a variety of metals and plastics. Individual manufacturers have specific designs and sizes for the particular needs of any potential installation.

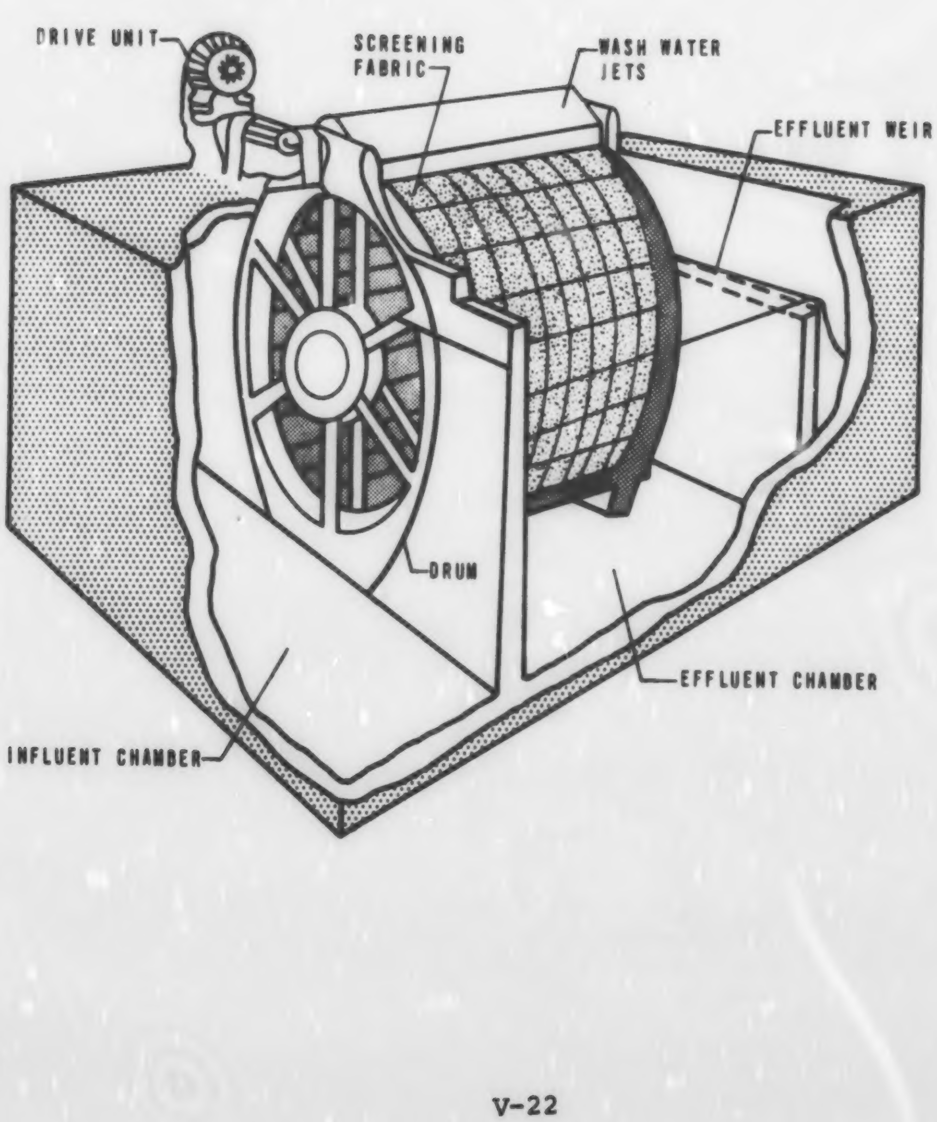
Although the microstrains have small openings, the openings themselves cannot account for the removal efficiency of the unit. Actually, the mat of previously trapped solids provides the fine filtration which characterizes the unit performance.

One of the advantages of using a microstrainer is its low head requirement. It is, therefore, advantageous to transfer secondary effluent, without pumping, to a tertiary microstraining installation in order to minimize the shear forced imparted to the fragile biological floc.

Operational data from various installations indicate that the microstrainers using 23-micron fabric exhibited average

FIGURE V-6

TYPICAL MICROSTRAINER UNIT (1)


DRIVE UNIT
SCREENING FABRIC
WASH WATER JETS
EFFLUENT WEIR
DRUM
EFFLUENT CHAMBER
INFLUENT CHAMBER

solids removals ranging from 57 to 89 percent, while the 35-micron fabric exhibited removals of 55 to 73 percent. In practice, the coarser 35-micron fabric is generally used for the removal of coarse solids. Maintenance of microstrainers can be quite costly, since most units will require cleaning at least once a week.

Moving-Bed Filters

In addition to coarse, mixed, and multi-media filters, a new filtering technique known as a moving-bed filter (MBF) has been developed by Johns-Manville Corporation. A schematic of the MBF is shown in Figure V-7. The unit is basically a sand filter, but as the filter surface becomes clogged, the filtering medium is moved forward by means of a hydraulically-actuated mechanical diaphram. The clogged filter surface is removed mechanically or by gravity, to the extent that a fresh and clean filtering surface is exposed to the incoming chemically treated liquid. The unit is thus a form of countercurrent extraction device which has the capability of functioning on a continuous basis and does not have to be taken off stream for cleaning or backwashing.

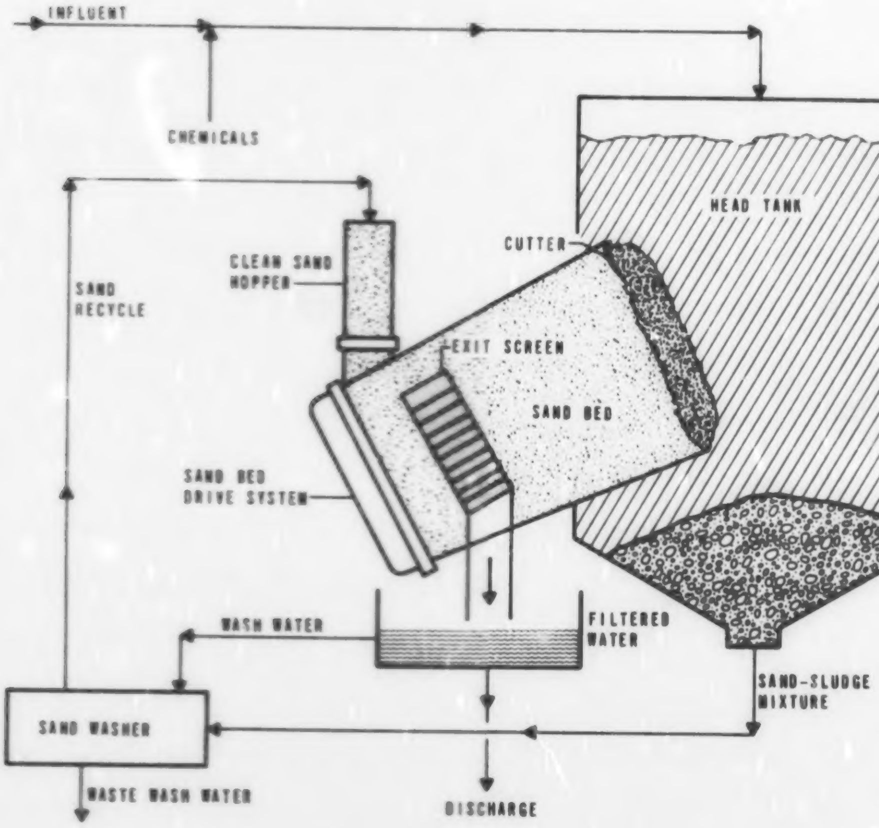
Land Treatment

Approaches for spreading treated effluent on the land can be classified into the following three main groups:

1. Rapid infiltration-percolation.
2. Overland flow or spray runoff.
3. Irrigation.

FIGURE V-7

SCHEMATIC OF THE MOVING-BED FILTER (MBF) (1)


INFLUENT
CHEMICALS
HEAD TANK
CUTTER
CLEAN SAND HOPPER
SAND RECYCLE
EXIT SCREEN
SAND BED
SAND BED DRIVE SYSTEM
WASH WATER
FILTERED WATER
SAND-SLUDGE MIXTURE
SAND WASHER
WASTE WASH WATER
DISCHARGE

Rapid infiltration-percolation consists of dosing the contents of storage basins on an intermittent basis to maintain high infiltration rates. The main portion of the wastewater enters the groundwater after filtering through the soil. Additional losses are attributed to evaporation. Satisfactory soils for this application must be highly permeable and exist in thick layers. Typical soils are coarse textured sands, loamy sands, or sandy loams.

Overland flow is the controlled discharge of effluent, by spraying or other means, onto the land with a large portion of the wastewater appearing as runoff to streams. Soils suitable for this method are clays and clay loams with limited permeability. The treatment site should have a moderate slope.

The overland treatment process has been developed in the United States for treatment of high-strength wastewater, such as discharges from canneries. This process has not been used in this country for treatment of municipal wastewater. Operational experience covering a number of years in Australia indicates BOD_5 and suspended solids removals of approximately 95 percent for municipal discharges.

Irrigation is the controlled discharge of effluent, by spraying or surface spreading onto land to support plant growth. Maximum quantities of applied wastewater are directly related to the requirements of crops grown. Although overland flow and rapid infiltration-percolation may have merit under special circumstances, irrigation is probably the best land application process for use in Iowa at the present time.

Current technology indicates that the equivalent of secondary treatment of domestic wastes should be provided prior to land application. Treatment is important for reasons of public health, odor control, solids removal, operational efficiency, and reliability. Normally the disinfected effluent from existing waste stabilization ponds and trickling filters can be applied to the land without further treatment.

Waste Stabilization Ponds

A major problem with waste stabilization ponds as presently designed is that a high quality effluent is not consistently produced. During warm summer days, large quantities of algae are discharged in the pond effluent and the effluent quality is primarily dependent upon this algal content. If the algae can be removed, a satisfactory suspended solids and BOD_5 quality will be produced. The central problem is how to remove dispersed algal growth.

A number of methods have been produced to separate algae from wastewater. These include microstraining, and filtration, chemical precipitation, and centrifugation. However, each process has proven too complex and/or too expensive for routine use.

The most practical method for algae separation is the use of multiple-cell ponds. Multiple-cell ponds reduce short circuiting of wastewater flow and permit effective separation of algae through the use of subsurface draw-offs. Multiple cell ponds also allow flexibility of operation which is desirable because of the annual range of climatic conditions within the study area. Although numerous cells for algae removal appear desirable, experience indicates that more than three cells does not increase BOD_5 or suspended solids removal significantly.

Waste stabilization ponds are designed with sufficient retention time for controlled discharge. Approximately six months retention time is required for controlled discharge ponds anticipating discharge over only a few weeks during the year.

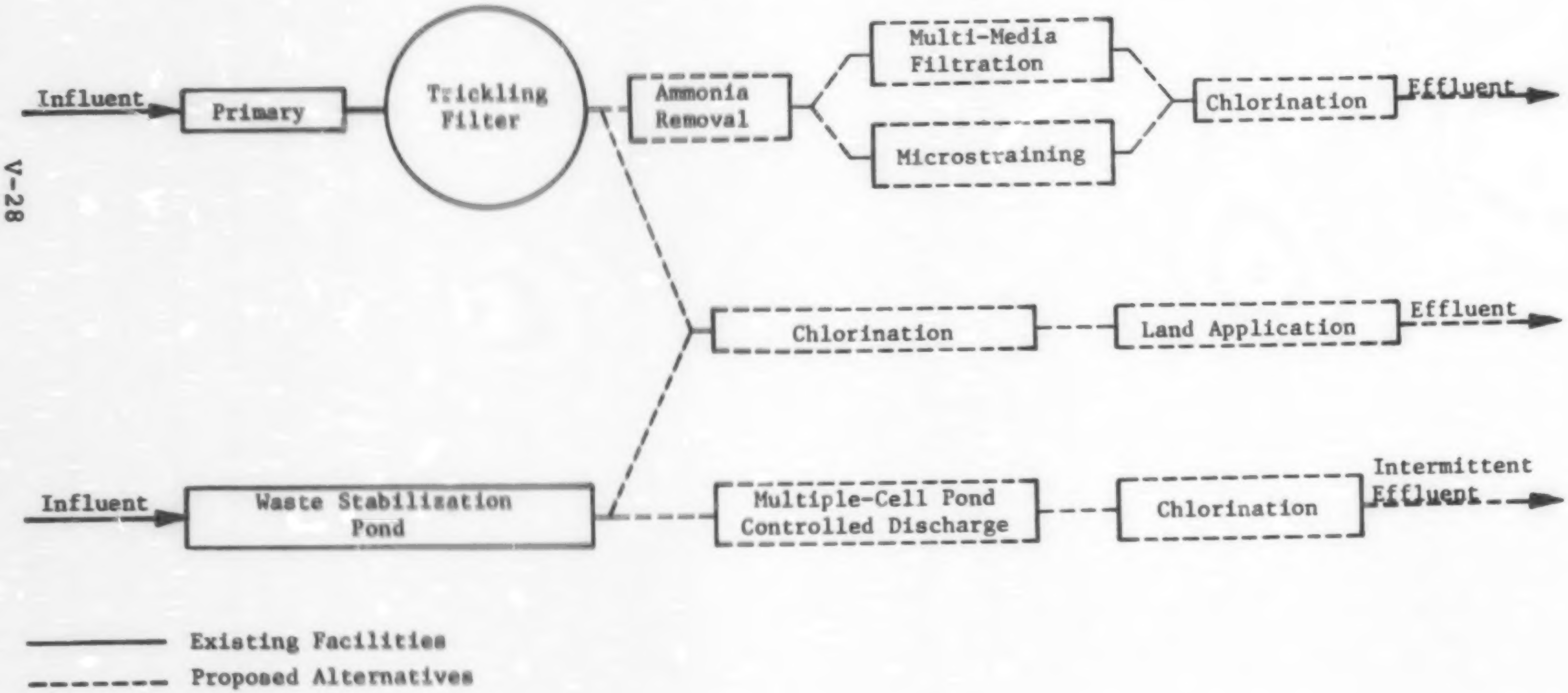
Advanced Waste Treatment Technology - Ammonia Conversion

Unit processes considered for converting ammonia nitrogen to nitrate nitrogen require facilities beyond existing secondary treatment. Figure V-8 presents the various feasible alternatives for use in Iowa.

Ammonia conversion is difficult in waste stabilization ponds during the winter due to the low temperature of the wastewater. Communities with waste stabilization ponds which provide 120-day storage may be exempt from the ammonia conversion requirement when EPA guidelines are finalized. However, for the purpose of this study all waste stabilization pond systems serving municipalities have been projected to be upgraded to three cell, 180-day storage facilities.

FIGURE V-8

ADVANCED WASTE TREATMENT TECHNOLOGY - BOD REMOVAL


Influent
Primary
Trickling Filter
Ammonia Removal
Multi-Media Filtration
Microstraining
Chlorination
Effluent
Chlorination
Land Application
Effluent
Influent
Waste Stabilization Pond
Multiple-Cell Pond Controlled Discharge
Chlorination
Intermittent Effluent
Existing Facilities
Proposed Alternatives

Biological nitrification basically consists of oxidizing ammonia to nitrate. Nitrification is both temperature and pH dependent. The rate of nitrification increases approximately linearly with increasing temperature through the normal temperature range of municipal wastewater. The optimum pH for nitrification is approximately 8.4.

Few wastewater treatment plants are currently operating to effect nitrification, but several are in the design and construction stages. Actual full-scale plant operating data on the various processes is minimal.

A long solids retention time (greater than 10 days) is required to achieve efficient nitrification. When nitrification processes are designed to follow an existing secondary wastewater treatment plant, the existing facility must produce a reasonably high quality effluent (around 50 mg/l).

If the plant is overloaded or in poor condition, a high BOD_5 loading will be discharged to the nitrification facilities. Under this situation, the nitrifiers will either be lost in the effluent or the waste sludge. Particular operational problems are most likely to occur during cold weather when biological processes are least efficient.

Pulsed Adsorption Bed

The pulsed adsorption bed process is synonomous with the activity of the media. Influent waste is mixed with air and then passed upward through a bed containing sand, carbon, or plastic media. Lifting action of the wastewater and air causes the sand bed to pulsate. A portion of the organic material in the influent is used by the microorganisms attached to the media.

No full-scale facilities are operating, but laboratory investigations conducted by Iowa State University have been encouraging. Ammonia conversion efficiencies are comparable with suspended growth nitrification. Based upon influent ammonia concentrations at 15 mg/l, effluent concentrations less than two mg/l have been obtained under hydraulic loadings between three and five gpm/sq. ft.

The major advantage of this system is the minimal operator time required to produce quality effluents. In addition, operation of pilot facilities have shown little tendency for these units to clog due to solids build-up within the media. Apparently the continual pulsing of the bed, combined with adequate distribution of air flow, allows the system to remain free of clogging problems.

The major disadvantage associated with this process is the increased head required to flow through the media bed. Under typical operating conditions, an allowance of approximately seven to eight feet is required to operate the system. Another disadvantage is the possible clogging of air ports in the air distribution system when the unit is not in operation.

Activated Sludge

The physical facilities used for an activated sludge nitrification process (i.e., suspended growth) are similar to those used for conventional secondary treatment. Aeration basins, blower facilities, effluent clarifications, and return sludge facilities are all required. The major difference is that facilities designed for nitrification will normally require a longer hydraulic and solids detention time.

Operation of these facilities will be most difficult during the winter months due to the lowered wastewater temperature following the trickling filters. Although the rate of reaction is drastically decreased, nitrification will occur at wastewater temperature between 41 and 50 degrees (5 to 10 degrees C) if the pH is near 8.4 and the dissolved oxygen concentration is maintained between 3.0 and 4.0 mg/l. However, operation at this elevated dissolved oxygen concentration increases the quantity of air required.

Maximum organic loading (BOD_5) under which the process can operate effectively is not well defined. Short-term shock loads in excess of 50 mg/l BOD_5 can be adsorbed without permanent upset. Where BOD_5 loadings are excessive, the organisms responsible for carbonaceous removal will multiply rapidly and the slower growing nitrifiers will be lost in the waste sludge. Once the nitrifiers are lost, it is extremely difficult to rebuild satisfactory populations when wastewater temperatures are low.

Filter Towers

Operation of a filter tower consists of passing wastewater downward through a tower containing synthetic media at depths of approximately 20 to 25 feet. As the wastewater flows through the tower, the biological slime growth on the media converts the influent ammonia to nitrate nitrogen. The large void space provided in the synthetic media provides ample natural draft ventilation for counter-current air and liquid flows.

Although these installations have been used in numerous locations for handling industrial and municipal wastewaters, limited data have been collected describing the results of ammonia conversion. Typical values indicate that influent concentrations of 15 mg/l may be reduced to less than two mg/l in the effluent. Loading rates vary with the wastewater that is applied to the unit process.

The major advantages associated with this system are the large specific surface areas, the high percentage of void space, the efficient aeration mechanism at the liquid-air interface, the continuous wetting of the microbial growth, and the simplicity of operation.

The major disadvantage associated with this process is the additional pumping facilities required to apply the wastewater to the 20 to 25 foot high tower.

Breakpoint Chlorination

Breakpoint chlorination consists of using large dosages of chlorine to oxidize ammonia to nitrogen gas. The efficiency of chlorine as an ammonia oxidant depends upon pH, temperature, organic matter concentration, and contact time. Most studies indicate that approximately 10 mg/l of chlorine are required for each mg/l of ammonia nitrogen in the wastewater. In addition to the resulting nitrogen gas, some chloramines will be formed and may be detrimental to aquatic life. Proper pH control can limit formation of chloramines.

After breakpoint chlorination, some form of dechlorination may be required to remove excess free chlorine which may endanger aquatic life in the receiving water. Methods used for dechlorination include aeration of the effluent, filtering through a granular carbon bed or addition of sulphur dioxide to the effluent.

A prime advantage of breakpoint chlorination is the flexibility of the system. If continuous nitrification is not required, the process can be shut down during certain seasons of the year. Since breakpoint chlorination converts ammonia directly to nitrogen gas, use of this process eliminates the need for construction of dentrification facilities.

One drawback to utilizing breakpoint chlorination is that while ammonia concentrations in the wastewater are reduced limited reduction of other wastewater parameters is achieved. The process will not reduce suspended solids of COD concentrations and will increase the total dissolved solids content of the effluent. Breakpoint chlorination reduces the BOD reaction rate and BOD_5 values will be lowered, however, ultimate BOD values will remain unchanged. For most communities, additional processes will be required, in addition to breakpoint chlorination, to satisfy suspended solids and BOD_5 effluent limitations.

Bio-Discs

In this process, a large diameter corrugated plastic media are mounted on a horizontal shaft and placed in a tank. The media is slowly rotated with about 40 percent of the surface area always submerged in the flowing wastewater. The process is similar in function to the trickling filter except the bio-mass is passed through the wastewater instead of the wastewater being passed over the bio-mass.

Removal efficiencies are comparable to those associated with previously discussed nitrification facilities. Under loading rates in the range of two to three gpd/sq. ft., influent ammonia concentrations can be reduced from 15 mg/l to approximately 2 mg/l.

The main operational advantage this system has when compared with either the activated sludge nitrification process or the filter tower system is that no sludge or effluent recycle is required. In addition, the actual head loss required to operate these facilities is less than two feet. As with the filter tower, no mechanical aeration facilities are required to supply oxygen to the bio-mass.

Advanced Waste Treatment - BOD Reduction

To meet BOD_5 effluent limitations, existing trickling filter plants could use either multimedia filtration, microstraining, or land treatment. Either multiple-cell ponds or land application could be used to treat existing waste stabilization pond effluent. These facility combinations are identified on Figure V-9.

Use of these processes may satisfy the required BOD_5 effluent limits. Earlier discussions relating to multimedia filtration, microstraining, polishing ponds, multiple-cell ponds, and land treatment are applicable to this treatment level.

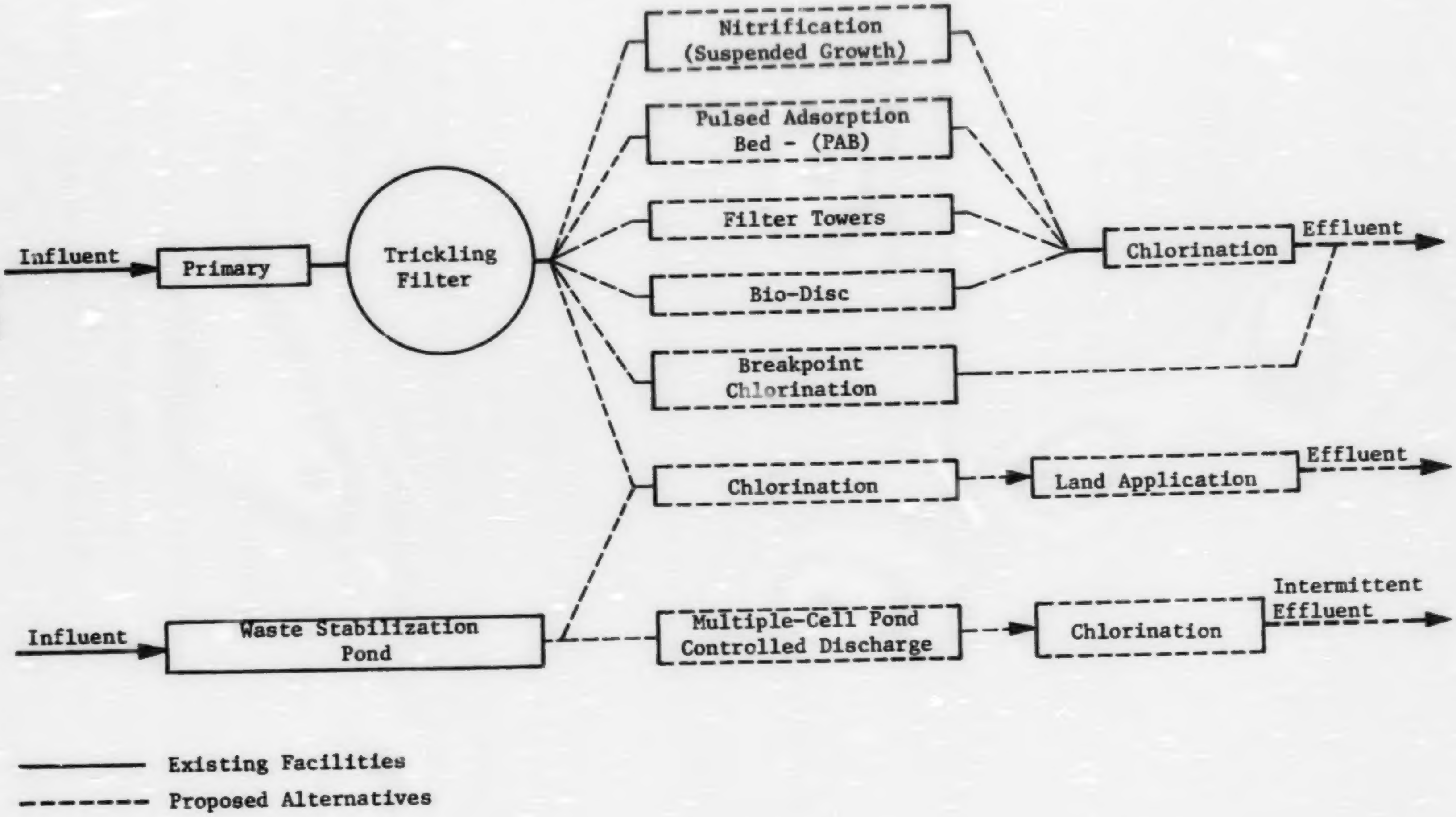
SOLIDS HANDLING AND DISPOSAL

For most waste treatment facilities, solids handling and disposal represents from 30 to 50 percent of the total treatment costs. Thus, to establish cost-effective treatment methods, specific attention should be directed toward solids handling and disposal along with liquid treatment procedures.

No single system is capable of solving all problems. Each method has advantages and works well under a given set of local conditions, while in other areas a different system

FIGURE V-9

ADVANCED WASTE TREATMENT TECHNOLOGY - AMMONIA CONVERSION


Influent
Primary
Trickling Filter
Nitrification (Suspended Growth)
Pulsed Adsorption Bed - (PAB)
Filter Towers
Bio-Disc
Breakpoint Chlorination
Chlorination
Effluent
Chlorination
Land Application
Effluent
Influent
Waste Stabilization Pond
Multiple-Cell Pond Controlled Discharge
Chlorination
Intermittent Effluent
Existing Facilities
Proposed Alternatives

may be better suited. Limitations on the use of various methods include process sensitivity to the quantity handled, climatological effects, land area, soil constraints, and technology development.

Alternative Systems

There are a number of alternatives including thermal conditioning and stabilization, incineration, combustion processes such as pyrolysis or drying, product recovery including soil conditioner or compost, transport methods such as rail or barge, etc. All of these sludge unit operations have limited application due to the size of existing facilities.

Most additional liquid treatment unit processes considered for upgrading existing secondary treatment facilities yield relatively small amounts of additional sludge for processing and disposal. Thus, the additional capital and operational investments required for new facilities will primarily be associated with liquid treatment. Additional expenditures required for solids handling will be small compared to the existing primary and secondary operations.

Thickening - Use of gravity thickening facilities for most installations in the basin is probably desirable. Flotation thickening and centrifugation is particularly desirable for the low concentration activated sludges. Both flotation thickeners and centrifuges generally require more operating personnel and thus, are generally less desirable for this area. For some of the small facilities (less than 0.5 mgd), subsequent processing without a thickening step is likely to be the cost-effective approach.

Conditioning and Stabilization - Nearly all sludges generated in the state are being disposed of in landfills or by land spreading. These disposal methods require some previous stabilization steps to avoid any environmental degradation. Aerobic digestion is particularly appropriate for the smaller facilities where blowers are already installed or required for the liquid treatment operations. Aerobic digestion has disadvantages associated with high power requirements and low efficiencies for communities located in the extreme northern areas of the basin.

Anaerobic digestion, although sometimes difficult to control, is a desirable stabilization step. Particular attention should be directed toward this process when conservation of energy is critical. Proper operation of anaerobic digestors produces readily dewatered sludge and significant amounts of methane gas. Enough gas is produced to provide head for the anaerobic digestion process itself and for treatment facilities buildings, thus resulting in an energy and economic savings.

Where mechanical dewatering is used, some form of chemical conditioning is common. Most areas find the use of lime and/or ferric chloride to be appropriate and economical.

Dewatering - If sludge is to be disposed of in a wet condition on land following digestion, no dewatering is practiced. For small facilities that dewater prior to disposal, drying beds provide a cost-effective solution. Sufficient storage should be provided in digestion units to allow flexibility in drying bed operation.

An alternative to drying beds is the use of drying lagoons. These have been used in some instances where land is inexpensive. However, without close operator attention, such lagoons can become an environmental problem and generally are not acceptable for the basin.

For larger plants (greater than 1.0 mgd), the use of mechanical dewatering equipment will offset the large area and manpower needs associated with drying beds. The use of vacuum filters is the most widely applied mechanical dewatering method in the United States and will generally be appropriate for facilities in Iowa. This method is well established for removing moisture from sludge after digestion. Vacuum filters can normally achieve from 20 to 30 percent solids concentration in the filter cake after dewatering.

Either filter presses or centrifuges are alternatives to vacuum filters. Filter presses are generally higher in cost than vacuum filters, but achieve a dryer cake (solids concentrations in the range of 30 to 50 percent). When a combustion process follows the dewatering operation, these units are particularly desireable to minimize fuel requirements. However, the incineration process is probably too expensive for most of the facilities located in the basin.

Centrifuges offer advantages over vacuum filters through requiring smaller space and generally lower initial costs. Where space at a treatment site is not critical, however, higher operating and maintenance costs as well as poorer solids capture offset these advantages.

Transportation

The two principal methods available for transporting sludge in the basin include truck and pipeline. Alternative means, such as rail or barge, are normally feasible only for extremely large volumes.

Use of trucks for transporting either liquid or dewatered sludge is quite feasible for small communities where haul distances are not exceptionally long. Trucks also offer flexibility in operation since they are capable of hauling to a number of alternate disposal sites.

Transport of liquid sludge in a pipeline for land spreading is economical where distances are fairly long and the final disposal site is reasonably fixed for a number of years.

Ultimate Disposal

The three most feasible methods of sludge disposal in the basin include sanitary landfill, lagoons, and land spreading. Using sanitary landfills for disposal of sewage sludge in combination with refuse is normally an economical operation. Sewage solids tend to sift among the voids in compacted refuse, and some nominal economies in land required for disposal are achieved. Combining the two waste materials in one facility is also desirable from a management standpoint.

Sludge lagoons may provide an alternate disposal technique where an abundance of land is available. In general, this procedure is not recommended since the material can often produce objectionable odors if the stabilization step is not operated properly.

Land spreading is currently used by a number of small municipalities and is a cost-effective alternative to using a sanitary landfill. The land spreading technique is appropriate for either wet or dewatered sludge. Either method uses the soil conditioning characteristics of the sewage solids effectively. Proper monitoring and close attention to application procedures are required to avoid any potential environmental difficulties. Land requirements for spreading are greater than for landfill. Consequently, this method is particularly feasible where sufficient land area is available.

Other Processing Operations

Many other handling operations have been tried and are in use at other installations. Some of these include improved thickening through oxygen activated sludge; thermal conditioning to eliminate chemical costs and improve vacuum filter yield; incineration to reduce the volume required for hauling and disposal; and pyrolysis, heat drying, and composting which have product marketing objectives. These processes are either in a state of technical development, lack good market outlets for sludge products at this time, or are generally not appropriate to the basin for other reasons.

Conclusions

The ability of wastewater treatment plants to perform at required levels of efficiency becomes more critical as water pollution abatement programs achieve their objectives. Deviations from design performance, which were formally of lesser consequence, now become paramount because of their impact on the receiving waters. Improved process monitoring and plant operation will obviously reduce the incidence of inadequate performance, but many cases are the result of more basic deficiencies in the treatment system. Such deficiencies can arise from: 1) inadequate initial design or 2) increased or changed load applied to the system. Another consideration in achieving the required levels of efficiency is the upgraded treatment required to maintain the desired water quality in the receiving waters.

Regardless of the cause, the result is that an inadequately treated effluent is discharged. The historical solution to such a problem has been plant expansion along the same lines as the original facility, or addition of conventional unit processes to add secondary or, in a relatively few cases, tertiary treatment to the system. Depending on its application, a generalized approach such as this does not necessarily make optimum use of the previously existing facilities nor of the expanded facilities.

Upgrading of wastewater treatment plants may be required to handle higher hydraulic and organic loadings to meet existing effluent quality and/or to meet higher treatment requirements. Any of these situations requires optimization of existing facilities before consideration of additional treatment facilities. It is necessary that a distinction be made between upgrading to accommodate higher hydraulic and organic loads, and upgrading to meet stricter treatment requirements. Existing facilities can be made to handle higher hydraulic and organic loads at slightly reduced treatment requirements. But an increased treatment requirement usually requires significant expansion and/or modification of existing facilities.

Rapid urbanization, development of industries, and stricter treatment requirements often necessitate unanticipated upgrading of treatment plants or premature implementation of upgrading programs. Many existing treatment plants are not capable of meeting the more stringent performance levels required by today's water quality standards. In addition, there are needs for interim improvements. These considerations, plus economic pressure to optimize pollution abatement expenditures, make it mandatory that a logical and technically sound approach to upgrading existing treatment facilities be established. This is especially true because of the numerous alternatives available for consideration prior to the selection of a method for upgrading an existing facility.

The alternative advanced waste treatment processes should not be considered as measures to correct deficiencies in existing plants. If existing facilities are overloaded, and excessive loads are placed upon the advanced processes, the desired degree of treatment will not be achieved. Where existing facilities are presently producing a high quality effluent, operation should continue at the same high standard. If preliminary treatment processes are neglected with the thought that a later polishing process will handle everything, the total plant will not produce the quality of effluent for which it was designed.

Additional manpower and a more highly skilled labor force will be required to operate the upgraded plants. Additional facilities will require more operation and maintenance, and in some instances, additional sludge will be produced which requires more labor. Higher skilled labor is particularly needed where communities will be required to practice ammonia conversion.

In some instances, it may be desirable to construct a new wastewater treatment plant rather than upgrade the existing one. There are many factors involved in this decision. The desirability of continuing to operate a treatment plant at the present site; the physical condition, life expectancy, and capacity of the existing treatment units; and the current and anticipated effluent requirements must all be carefully considered. Each situation is obviously unique and detailed analysis must be performed during facilities planning to reach adequate decisions.